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THE FUNDAMENTALS OF RADIO

BY

R. R. RAMSEY Ph.D.

Professor of Physics, Indiana University, Member Inst. Rad. Eng.; Fellow Am. Phys. Soc.; Fellow A. A. A. S.; Fellow Ind. Acad. Science; Author, "Experimental Radio."

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PREFACE

In the Fundamentals of Radio I have endeavored to give the basic theory of radio as it is exemplified in modern practice. Perhaps if the fundamentals were limited in number to two, they might be given as the resonant, or wave meter circuit and the three electrode-vacuum tube. This book will be found to be largely based on these two conceptions. An elementary knowledge of electricity such as that usually given in a first course in Physics is assumed. Although I have endeavored to give a non-mathematical treatment of the subject, some Calculus has been introduced in a few sections. These mathematical sections have been developed and explained in a way which I hope will be helpful to the non-mathematical reader. The text has been illustrated by a large number of diagrams and pictures of radio apparatus. It has not been my purpose to illustrate all the modern circuits and "hookups." A few typical circuits are given to show how the fundamentals are applied in modern practice.

I am indebted to Mr. Carl Dreher and Mr. John V. L. Hogan for helpful suggestions, to The General Radio Co.; Weston Electrical Instrument Co.; Leeds Northrup and Co.; Thordardson Electric Co.; Allen D. Cardwell Co.; Ceco Manufacturing Co.; Samson Electric Co.; The Electric Specialty Co.; Kodel Manufacturing Co., and Q. S. T. for cuts and information; to The Western Electric Co., Federal Telegraph Co., Kolster Radio Corporation, National Carbon Co., Radio Corporation of America, The R. C. A. Photophone Co., Jensen Radio Manufacturing Co., Dubilier Condenser Co., Bell Telephone Laboratories, Jewell Electrical Co., The Radio Marine Corporation and the Radio Division, Dept. of Commerce for pictures, diagrams and information.

R. R. RAMSEY

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R. R. RAMSEY

The FUNDAMENTALS *of* RADIO

CHAPTER I

ELECTRICITY, DIRECT CURRENT

1. Introduction. The ancients at an early date noticed that certain substances such as amber, when rubbed had the property of attracting light objects. From these early experiments the study of static electricity originated. At a much later date it was discovered that electricity flowed through wires. From these experiments the study of current electricity developed.

2. Static and Current Electricity the Same. At the present time it is customary to speak of static electricity and current electricity. The ELECTRICITY in static electricity and current electricity is the same thing. One, static electricity, is electricity at rest, and the other, current electricity, is electricity in motion. The laws of static electricity and current electricity are not the same. This is also true of liquids. The laws of hydrostatic pressure of water in tanks and standpipes are not obeyed by water when it is flowing through pipes.

3. System of Units. From the study of static electricity and current electricity two systems of electrical units have developed, the Electro Static system and the Electro Magnetic system.

4. Electrostatic System of Units. The electrostatic system of units is based on the definition of unit quantity. The unit quantity is that quantity which will repel a like quantity—like in kind and dimension—with a force of one dyne when the two are placed one centimeter apart.

In radio about the only time we make use of the electrostatic system of units is in the calculation of the capacity of a condenser from the dimensions of the plates of the condenser.

5. The Electromagnetic System. The electromagnetic system is based on the fact that there is a magnetic field about a wire in which a current of electricity is flowing. The unit current is that current which will exert a force of one dyne on a unit magnetic pole when the current flows in a unit arc. The unit arc in this case is supposed to be made of a wire one centimeter long bent in the form of the arc of a circle which has a radius of one centimeter.

Of course, current could not flow if we have the wire only. The wire may have two lead wires attached and placed as in Figure 1, to conduct the current to and from the arc, or the wire can be bent into a circle of one centimeter radius as in Figure 2, in which case the force on the unit pole at the center, or the field at the center, is 2π dynes. A more general statement is to say that the magnetic field, H, due to a current, I, is $H = \int I ds/d^2 \cos\theta$, where ds is a short length of the current, I, in the wire. d is the distance of ds from the unit pole, or the point where the field is being calculated; θ is the angle between r and the normal to ds. The integral sign, $\int$, means a summation of all the effects which all the elemental lengths, ds, of current, I, produce. Figure 3 gives a general idea of the summation of effects.

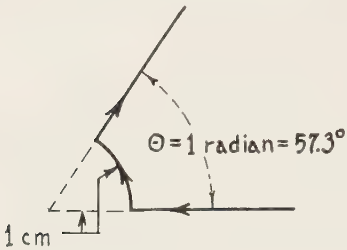


FIGURE 1.

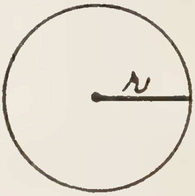


FIGURE 2.

The expression $H = I ds/d^2 \cos\theta$ is perhaps the fundamental law of current electricity.

6. *What is Electricity?* So far, electricity has not been defined. It is a standing joke that the only student who knew what electricity is had forgotten just at the instant the professor asked him. Although it is not known just what electricity is, it is known what it will do in some cases. It is known that electricity is made up of small charges or quantities called electrons. These electrons move or flow through the wire in the direction opposite to that in which the current is said to flow.

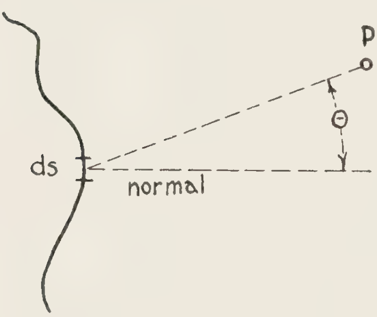


FIGURE 3.

7. *The Electron.* The analogy between electricity and a liquid is very close. The laws of static electricity are very analogous to

the laws of liquids at rest, and the laws of current electricity are much like those of liquids flowing through pipes. In electricity the thing that flows is the electron. The electron is a small negatively charged body whose mass is the one eighteen-hundredth (1/1800) part of the mass of the hydrogen atom, and whose charge, e, is $e = 4.774 \times 10^{-10}$ electrostatic units, or 15.91×10^{-19} coulombs.

The current in a wire is a flow of these negatively charged electrons. Since they are negatively charged they flow in the opposite direction to the direction we say the current flows. In the early days it was realized that electricity was conducted by wires or that something flowed and it became necessary to guess the direction of flow. There being two directions, the chances were even that the direction guessed would be the right direction. The guess was made that the current flowed through the wire from the copper terminal to the zinc terminal of a battery. It has turned out, since more is known about the flow of electricity, that the guess was wrong. However, we still use the old custom of saying that the current flows in a certain direction and then turn around and say that the electron flows in the opposite direction. This need not confuse us if we understand exactly what is meant.

In the ordinary three electrode vacuum tube we have a case of electron flow from the hot filament to the plate, but we say the current flows from the positive terminal of the B battery to the plate and then to the filament. If the battery is reversed there is no flow, since the negative plate repels the electrons and they remain in the hot filament and there can be no current.

A negatively charged body is one that has an excess of electrons. A positively charged body is one which has lost some electrons.

Experiments made in the last two or three years have thrown some doubt on just what the electron is. So we may still say we do not know just what electricity or the electron is. For purposes of this book we can saythat current electricity is a flow of electrons.

8. Magnetism. Before going very far with current electricity it will be necessary to speak of magnetism and magnetic substances. A magnetic substance is one that has the property of attracting other magnetic substances. Iron is the chief magnetic substance. Nickel and cobalt are the other two magnetic elements. Certain alloys made from a mixture of the non-magnetic elements are magnetic. Usually when speaking of magnets we mean iron

magnets. A magnet is a piece of iron or steel which has the property of attracting other iron bodies.

9. Poles. The magnet has two poles. The north pole is the one which points north if the magnet is suspended so that it can turn freely. The south pole is the one which points south. North poles attract south poles and south poles attract north poles. Unlike poles attract. A north pole will repel other north poles and south poles will repel other south poles. Like poles repel.

10. Law of Attraction. The law of attraction is that the force of attraction is proportional to the product of the pole strengths and inversely proportional to the square of the distance between, or, $F = mm'/d^2$ where m and m' are the pole strengths of the two poles and d is the distance between the two poles. The unit pole is one which will repel a pole, like in sign and dimension, with a force of one dyne when placed one centimeter from it. In the above it is assumed that we have two free poles, north poles, say. A free pole is a fictitious pole, since we cannot break a north pole off the end of a magnet. When we break the north end off we find that the broken end of the piece is a south pole. If we take two long magnets we can have the magnets long enough so that the south poles are so far removed that for all practical purposes the north end is a free pole.

11. Magnetic Moment. Magnetic moment of a magnet is the product of pole strength of the magnet times the length of the magnet, or the magnetic moment, $M = ml$.

12. Magnetic Field. The strength of the field of a magnet, or the field strength at a given point is numerically equal to the force which the magnet will exert on a unit pole if the unit pole is placed at the point in question.

From the equation $F = mm'/d^2$, we have the field, $H = m/d^2$, m' being unity. From the above we get $F = Hm'$. The force on a pole at P is equal to the field at P times the strength of pole which is at P. It will be noted that the field at any point P is, $H = m/d^2$. This is true if there is or is not a pole at this point. We speak of the earth's field as having such a value at a certain point. The nearest magnetic pole may be the pole of the earth near Hudson Bay.

13. Magnetic Potential. The difference of magnetic potential between two points is numerically equal to the work done in moving a unit positive, north pole from one point to the other.

In Figure 4 let m be a free north pole, let A and B be the two points, between which the difference of potential is to be found. Let us assume that we carry a unit north pole from B to A. Work is the product of force times space. The force at A is greater than the force at B. It is clear that if we use the force at A the product of force times distance AB, or the work will be too large. If we use the value at B the work will be too small. We must use an average value of the force. Since the force varies as the inverse square of the distance we must use the geometric average or the square root of the product of the two. The force on the unit pole at A is m/d_1^2, that at B is m/d_2^2. The geometric average is $\sqrt{m^2/(d_1^2 d_2^2)}$. The space is d_2-d_1. The work is $m(d_2-d_1)/d_1 d_2$. This is equal to $V_1-V_2=m(1/d_1-1/d_2)$, which is numerically equal to the difference of potential between the two points. If d is made equal to infinity or if the point B is at infinity, then

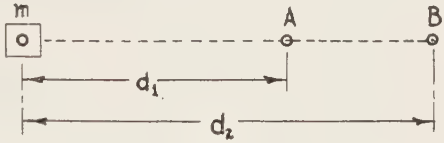


FIGURE 4.

$$V_2=\frac{m}{d_2}=\frac{m}{\infty}=0 \quad \text{and} \quad V_1=m/d_1 \quad \text{or} \quad V=\frac{m}{d}$$

14. Potential at a Point. Potential at a point is numerically equal to the work done in carrying a unit north pole from infinity to the point. In practice we do not measure potential at a point. We always measure the difference of potential between two points. When we speak of the potential of a point we mean the difference of potential between the potential at this point and the potential of some other object, usually the earth. The earth is for convenience assumed to be zero potential. In the same manner we speak of the elevation of a point as being so many feet. We usually mean so many feet above sea level. No one knows how high the sea is; its height is arbitrarily taken to be zero for convenience.

Summing up the above we have:

The field H about a free pole varies inversely as the square of the distance from the pole. The potential, V, varies inversely as the distance from the pole m.

Care must be taken in using the term potential to distinguish it from the work done in moving a unit pole. The unit of work is the erg. The unit of potential is not the erg. The potential is numerically equal to the work done if the pole is unity.

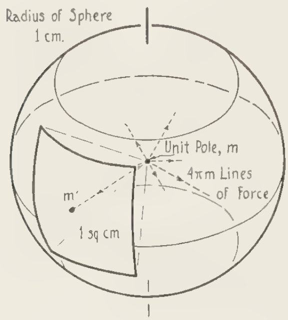


FIGURE 5.

15. Number of Lines from a Pole. Figure 5 represents a unit north pole, m, at the center of a sphere whose radius is one centimeter. On the surface of this sphere a second unit north pole, m', is placed. The force on m' is one dyne. The field at m' is unity, or one line per square centimeter. The surface of the sphere is 4π square centimeters and since the field is uniform over the surface the total number of lines coming from the unit pole, m, is 4π lines. If the pole has a strength of 10, the number of lines will be $4\pi \times 10$. The number of lines of force from any pole is $4\pi m$ where m is the pole strength.

The direction of a line of force is out or away from a north pole and towards or into a south pole. Lines of force start from a north pole and end on a south pole.

Figure 6 represents two actual north poles on the end of long magnets. If the south poles are far enough away so that the force due to them can be neglected, the north poles can be considered to be free north poles.

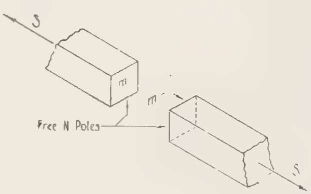


FIGURE 6.

16. Electric Fields and Potentials. We have derived the magnetic field and the magnetic potential at a point and the number of lines of force from a magnetic pole. In electricity we can define the electric field, and electric potential and the number of electric lines of force from a unit quantity in the same general manner. Thus a unit charge is that charge which will repel a like charge with a force of one dyne. Two points have unit difference of potential when it requires one erg of work to move a unit charge of electricity from one point to the other point. The unit of electric field at a point

is the field such that the force on a unit charge is one dyne if the unit charge is placed at the point.

17. Practical System of Units. For most purposes electrical quantities are expressed in the practical system. The unit of current is the ampere. The ampere is one-tenth of the absolute E.M. unit. Ten amperes produce a field of one gauss at the center of the unit arc when flowing through it.

The unit of quantity is the coulomb. The coulomb is the quantity of electricity which flows past a given point in a wire in one second when the current is one ampere. It is one-tenth of the absolute unit of quantity.

18. Electromotive Force. Electromotive force is that in a battery or generator which tends to make the electricity move. The practical unit of E.M.F. is the volt. This is 100 million (10^8) times the absolute unit of E.M.F. which is defined as that difference of potential between two points such that it will require 1 erg of work to move 1 unit of quantity (10 coulombs) of electricity from the point B of low potential to the point A of high potential.

The volt can also be defined in terms of cutting lines of force. If a conductor moves through a magnetic field we say the lines of force are cut by the conductor. If we think of lines of force between two poles as invisible lines, bristles or whiskers sticking out of a north pole, then, when the conductor moves so as to pass through these lines, the E.M.F. induced in the conductor is numerically equal to the number of lines cut per second. To induce an E.M.F. of one volt, 10^8 lines must be cut per second.

If the current flows of its own accord from the point A to the point B, 1 erg of energy will be given out by the current. If two points have a difference of potential or E.M.F. of 1 volt and 1 ampere flows for 1 second, the energy given out is $10^8 \times 1/10 = 10^7$ ergs. 10^7 ergs is 1 Joule. The Joule is the practical unit of energy or work. If the same current flows for 2 seconds, the energy is 2 Joules. Joules = volts × amperes × seconds.

Power is the rate of doing work, or the work done in 1 second by a current. The unit of power in the practical system is the watt. Watt = volts × amperes, or 1 watt = 1 Joule per second; Energy, $J = EIt$; Power, $W = EI$; The kilowatt is 1000 watts.

The unit of resistance, or the ohm, is defined in terms of the ratio of E to I, or $R = E/I$. Wire tables give the resistances of various sizes of wires.

19. Ohm's Law. Ohm's Law states that there is a definite relation between current, E.M.F. and resistance. It is usually written $I=E/R$, $R=E/I$ or $E=IR$. Where I is the current in amperes, E is the E.M.F. in volts and R is the resistance in ohms. Amperes equals the total E.M.F. in volts divided by the total resistance in ohms. In the above form it is applied to the entire circuit, E standing for the E.M.F., or that, in the battery or generator which causes the current to flow.

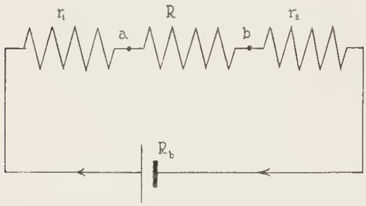


FIGURE 7.

20. Potential Difference and Electromotive Force. If we reserve the word "electromotive force" to apply to that which in a cell or generator causes electricity to flow, then there is no E.M.F. in a resistance. There may be a Pd. between the terminals. Thus there is a Pd. between the terminals a and b of the resistance box R, although there is nothing in the box itself which causes electricity to move. There is no E.M.F. in the resistance box. There is a Pd. between a and b due to the fact that it is connected to a battery which has an E.M.F.

Ohm's Law will apply to the resistance between a and b, $I_{ab}=\mathrm{Pd.}_{ab}/R_{ab}$. The current, I_{ab}, through the resistance R in this case, is also the current through the cell.

$$I=\frac{Pd_{ab}}{R_{ab}}=\frac{E}{R_{ab}+r_1+r_2+R_b}=\frac{E}{\text{total } R},$$

where r_1, r_2, R and R_b are the resistance as marked in Figure 7.

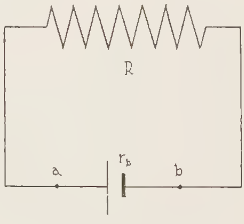


FIGURE 8.

The Pd. at the terminals of a cell equals the E.M.F. if there is no current flowing through the cell If there is a current flowing, the Pd. is less than the E.M.F. unless the cell has no resistance.

In Figure 8 where a cell is connected to a resistance R, we have, $\mathrm{Pd.}_{ab}=IR$, also $\mathrm{Pd.}_{ab}=E-Ir_b$, where $E=$ the E.M.F. and r_b is the resistance of the cell. The total Pd or fall of potential

around the circuit is equal to the E.M.F. Thus $Pd._{ab}=IR=E-Ir_b$, then $E=IR+Ir_b=I(R+r_b)$. The E.M.F., E, is equal to the current times the total resistance of the circuit. $Pd._{ab}$ is current times the resistance between the points a and b if there is no E.M.F. between these points. $Pd._{ab}=IR_{ab}$ is a useful form of Ohm's Law.

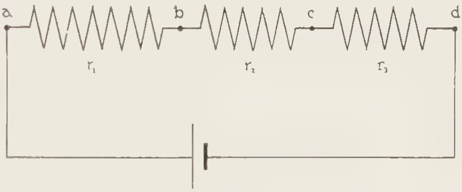


FIGURE 9.

21. Resistances in Series. If two or more resistances are connected in series as in Figure 9, then the total Pd. is equal to the sum of the separate Pd's.

$$Pd=Pd_1+Pd_2+Pd_3+\cdots$$

$$\text{But}\quad Pd=IR$$

$$Pd_1=I_1r_1$$

$$Pd_2=I_2r_2$$

$$Pd_3=I_3r_3$$

$$\text{But}\quad I=I_1=I_2=I_3$$

$$\text{Then}\quad IR=I_1r_1+I_2r_2+I_3r_3\cdots$$

$$\text{and}\quad R=r_1+r_2+r_3+\cdots.$$

22. Resistance in Parallel. If the resistances are connected in parallel as in Figure 10, then

$$I=I_1+I_2+I_3+\cdots$$

$$Pd=Pd_1=Pd_2=Pd_3$$

Then since $I=Pd/R$

$$\frac{Pd}{R}=\frac{Pd_1}{r_1}+\frac{Pd_2}{r_2}+\frac{Pd_3}{r_3}+$$

and then,

$$\frac{1}{R}=\frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3}$$

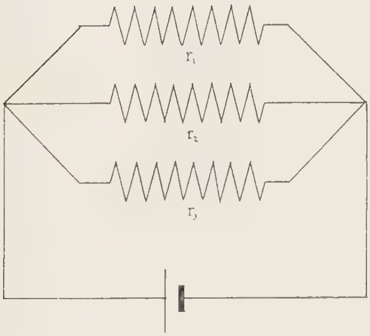


FIGURE 10.

since all the Pd's are equal. If there are two resistances in parallel, then $R=r_1r_2/r_1+r_2$.

If two resistances are placed in parallel the resultant resistance is less than the smaller of the two. Example, 100 ohms

and 1 ohm are placed in parallel, then $R = 100 \times 1/100 + 1 = 100/101 = .9909$ ohms.

The resultant resistance is a little less than the smaller of the two. If a big resistance is in parallel with a small resistance the result is almost as large as the smaller.

23. Instruments. Any good text book on Electricity will give a description of the mechanism of some of the various types of galvanometers, ammeters, voltmeters, and other instruments.

24. The Galvanometer. The galvanometer is an instrument consisting either of a small compass needle swinging at the center of a coil of wire or of a small coil of wire swinging between the poles of a horseshoe magnet. The deflection depends upon the current. In most of the swinging coil type (D'Arsonval) galvanometers the deflection is approximately proportional to the current. That is, when the current is doubled or trebled the deflection is doubled or trebled. Current can be measured by comparing the deflection produced by that current to that produced by a known current.

FIGURE 11.

25. The Voltmeter. The voltmeter is a portable D'Arsonval galvanometer with a resistance in series so that 1 unit of *Pd*, 1 volt or 1 millivolt will give one unit of deflection. 10, or any number of units of *Pd* will give a deflection of 10 or a deflection numerically equal to the *Pd* placed on the terminals.

Any sensitive galvanometer can be made into a direct reading voltmeter by placing the proper resistance in series with the galvanometer.

The assumption usually made is that the E.M.F. of a battery, is equal to the reading of the voltmeter. This is usually true, approximately. It is true if the resistance of the battery is small compared to the resistance of the voltmeter. $I = Pd/R_V = E/R_V + R_B$. Pd is equal to E if $R_V = R_V + R_B$. Thus if the battery resistance $R_B = 1$ ohm and the voltmeter resistance $R_V = 1000$ ohms,

$R_V = R_V + R_B$ to within 1 part in a thousand. Then $Pd = E$ to within 0.1%.

The current through a voltmeter is very small and usually is assumed to be zero. Weston Model I voltmeters take about 10 milliamperes for full scale deflections. Figure 11 is a picture of a Weston Model I Voltmeter.

26. The Ammeter. The ammeter is a portable galvanometer with a shunt across the terminals. This shunt is a strip of metal whose resistance is small. Any galvanometer can be made into a direct reading ammeter. Assume that our galvanometer has the proper resistance in series to make it into a direct reading millivoltmeter. If the shunt Figure 12 has a resistance of 1/1000 ohm, and the current through the shunt is 1 ampere, the Pd at the terminals is 1 millivolt, since $Pd = IR$ and the galvanometer will give a deflection of 1 division. Figure 13 shows the moving parts of an ammeter or voltmeter.

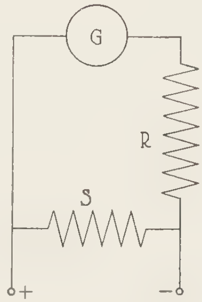


FIGURE 12.

The resistance of an ammeter should be small, since it is usually assumed to be zero.

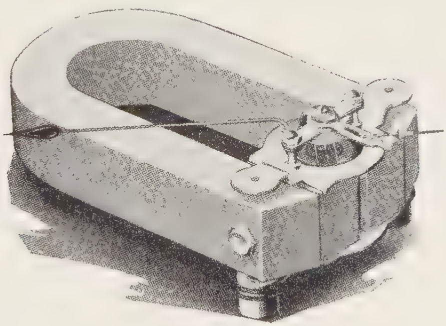


FIGURE 13. The galvanometer or moving parts of a Jewell ammeter.

27. Field about a Magnet. In a magnet we have two poles to consider. These poles are of equal strength and are at the ends of the magnet. The distance between the poles is l, the length of the magnet.

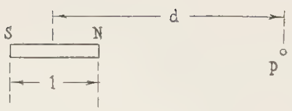


FIGURE 14.

In Figure 14 let NS be the magnet with pole strength m. The field at the point P which is at a distance d from the center, is the force on a unit north pole considered to be at P. The force due to the north pole is, $m/(d-\frac{1}{2}l)^2$. The force due to the south pole is $-m/(d+\frac{1}{2}l)^2$. This is negative, since attraction is always a negative force. The field is the algebraic sum of these two forces.

$$\frac{m}{(d-\frac{1}{2}l)^2}-\frac{m}{(d+\frac{1}{2}l)^2}=m\left(\frac{(d+\frac{1}{2}l)^2-(d-\frac{1}{2}l)^2}{(d-\frac{1}{2}l)^2(d+\frac{1}{2}l)^2}\right)$$

squaring the two parts of the numerator and adding, we have $m2dl/(d^2-\frac{1}{4}l^2)^2$. Since the magnetic moment, M, of a magnet is the pole strength times the length of the magnet or $ml=M$, then $H=2Md/(d^2-\frac{1}{4}l^2)^2$. If the distance d is great compared to the length l, then considering l to be zero, we have $H=2Md/d^4$ $=2M/d^3$. The field "end on" to a short magnet varies inversely as the cube of the distance. This "end on" position is sometimes called the first position of Gauss.

28. Potential at P "end on." The potential at P can be found in the same general manner. The potential "end on" will be since

$$V=M/d,\quad V_1-V_2=\left(\frac{m}{(d-\frac{1}{2}l)}\right)-\left(\frac{m}{(d+\frac{1}{2}l)}\right)$$

$$=\frac{ml}{(d^2-\frac{1}{4}l^2)}=\frac{M}{d^2-\frac{1}{4}l^2}=\frac{M}{d^2}$$

when d is great.

It is of interest to note that the negative of the space derivative of the potential is equal to the field. Writing $V=M/x^2$, then $-dV/dx=$ $+2M/x=H$. The negative sign is due to the fact that the potential diminishes as the distance x increases.

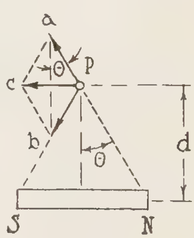


FIGURE 15.

29. Field at P "broadside on." If the point P is on a line perpendicular to the magnet, if P is broadside on, then we have the field or the force on the unit north pole as indicated in Figure 15. The force due to the north pole will be along the line Pa, and equal to

$m/(d^2+\frac{1}{4}l^2)$. The force due to the south pole will be along the line Pb, and the value will be $m/(d^2+\frac{1}{4}l^2)$. Let the values be represented by the length of Pa and Pb. The resultant field will be the vector Pc. Pc is equal to 2 $Pa \sin\theta$.

$$H=\frac{2m}{(d^2+\frac{1}{4}l^2)}\sqrt{\frac{\frac{1}{2}l}{(d^2+\frac{1}{4}l^2)}}=\frac{ml}{(d^2+\frac{1}{4}l^2)^{3/2}}=\frac{M}{(d^2+\frac{1}{4}l^2)^{3/2}}$$

If l is small in comparison with d, then, $H=M/d^3$.

30. Potential "broadside on." The potential at P is found in the same general way except that potential is a scalar quantity and since the potential at P due to the north pole is positive and the potential due to the south pole has the same numerical value but is negative, when added their sum is zero. It can be shown that although the potential is zero the space derivative of the potential with respect to the direction perpendicular to d is not zero but equal to the field, $H=M/d^3$.

31. Field Due to a Coil. If we apply the general equation $H=Ids/d^2 \cos\theta$ to a coil of radius r, Figure 2, we get $H=2\pi I/r$, $\cos\theta$ being unity and d being constant and equal to r.

If we apply this equation to get the value of the field at a point P, Figure 16, at a distance x from the center and on the normal to the plane of the coil at the center, we find that the field along the normal to the coil is $H=2\pi rI/(r^2+x^2)\sin\theta$. Since $\sin\theta=r/\sqrt{r^2+x^2})$. Then $H=2\pi r^2I/(r^2+x^2)^{3/2}$, and $H=2IA/(r^2+x^2)^{3/2}$ where $A=\pi r^2$.

FIGURE 16.

If the distance x is great compared to the radius of the coil, then $H=2IA/x^3$. We see that this equation is the same form as $H=2M/x^3$ for a short magnet.

If we let $IA=M$, the magnetic moment, and let $M=\alpha A$ where α is the magnetic moment per square centimeter, we have

$H=2\alpha A/x^3$. The field due to a current in a coil is the same as that of a thin magnet whose cross section is the same as the area of the coil. The current in the coil is here considered to be n times the current in one turn when the coil has n turns.

If the coil is considered to be a magnetic shell whose magnetic moment, $M = IA$ we have the field in the plane of the coil to be $H = M/x^3 = IA/x^3$.

The field in the plane of the coil is one-half of the field perpendicular to the plane. The fields have the same ratio, as they do in the case of a short magnet.

32. Lines of Force. When speaking of magnetic fields, it is customary to speak of lines of force. When H equals unity we say there is one line of force per square centimeter. There is one line of force between the unit poles when they are placed one centimeter apart. The unit of field intensity is the gauss. The number of lines of force per square centimeter is so many gauss per square centimeter. It is usual to express magnetic field intensity in absolute electromagnetic units. The gauss is a unit in the absolute system.

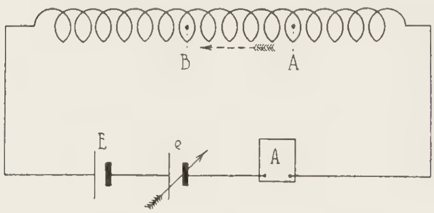


FIGURE 17.

33. Field in a Long Coil. Suppose we have a long coil or solenoid, Figure 17. This coil is supposed to be infinitely long, or at least long enough so there will be no effect due to the ends of the coil. If we have a free north pole, m at the point A, and move it to the point B, with the field H, which will be uniform if the coil is long, then the force on the pole m is $F = Hm$ and the work done will be $W = Hms$ where s is the space between the points A and B. If the pole is moved with the field H, there will be an induced E.M.F. in the coil which will be in the direction to oppose the current in the coil. Since we have supposed the field, H, to be constant we must suppose the current flowing in the coil must be constant. In order to keep the current constant we will suppose that we have a variable battery whose E.M.F. is e, in series with the regular battery E. It is supposed that we can vary the E.M.F., e, from zero to any value we please in order to keep the current, I constant. Thus the battery E.M.F., e, will be just equal and opposite to the induced E.M.F.

When the pole is at rest the work $W = EIt = I^2Rt$. When the pole is moving the work delivered by the batteries is $W + w = (E + e)It$

$= I^2Rt + eI$. Since I^2Rt is constant the work done by the moving pole, m, is equal to the energy delivered by the battery, e, is $Hms = eIt$. Since e is also equal to the induced E.M.F. caused by moving the magnet, $e = dN/dt$, or the rate of cutting lines of force. Then $eIt = I\int_B^A (dN/dt)dt = IN$ where N is the number of lines of force cut while the pole m, is moved from the point A, to the point B.

Then $N = 4\pi mns$ where n is the number of turns of wire per centimeter length of the coil, the number of lines from m being $4\pi m$. Then, $Hms = 4\pi mnsI$. Cancelling out m and s we have $H = 4\pi nI$. This is often written $H = 4\pi nI/10l$. In this case, n, is the total number of turns on the coil, l is the length of the coil, and I is the current in amperes.

34. Permeability and Magnetic Induction. If we have a long solenoid or a solenoid bent so the two ends are together so as to form a toroidal coil we have a field in the coil, $H = 4\pi nI/10l$. This is the number of lines per square centimeter when the core is filled with air. If the core is filled with iron then the number of lines per square centimeter, or the magnetic induction, B is $B = \mu H$, where μ is called the permeability. Thus the permeability, μ, is the ratio of the number of lines of force when the space is filled with iron, to the number of lines when the space is filled with air, or $\mu = B/H$.

35. Flux Through an Iron Core. The total flux through an iron cored solenoid is the induction times the cross section of the iron. $\text{Flux} = \mu H\square$ where $\square$ is the cross section.

$$\text{Flux} = \mu 4\pi nI\square/10l.$$

$$\text{Flux} = \frac{4\pi n(I/10)}{l/\mu\square} = \frac{MMF}{\text{Reluctance}}$$

MMF stands for magnetomotive force or that which causes "magnetism to flow." The similarity to Ohm's law will be noted.

The term n in the above formula stands for the total number of turns of wire in the coil. If the coil is an air core coil the winding must be uniformly distributed along the length of the coil. If the coil is an iron core coil, such as an ordinary transformer where the flux follows the iron path, it does not make much difference whether the turns are bunched or uniformly distributed.

36. Direct Current Machines. It is beyond the scope of this work to go into the details of construction of D.C. machinery. The shunt motor and generator are the most common type D.C. machines with which one dealing with radio will come in contact. The armatures of most modern machines are closed coil drum windings. The normal voltage, speed, and maximum load of the machine are given on the name plate.

It has become customary to use small machines to furnish the plate potential for power tubes used in radio transmitters and radio telephones.

37. Motor Used as Generators. A D.C. motor can be used as a generator, since the general construction is the same in each. Most small D.C. motors are designed for 110, 220, or 500 volts. The voltage of any machine depends upon the speed and the strength of the field. By increasing the speed the voltage can be raised. The shunt field windings are designed to have the required resistance to give the normal field current when connected to the rated voltage of the machine. If the armature is speeded up until the voltage is increased to twice the normal voltage the shunt field current will be excessive and there is danger of burning the field windings. Insert resistance in series with the field until the current in the field coil is the normal field current. The armature current when supplying tubes, will usually be very small. The danger with the armature is that it may not mechanically stand the high speed and that the insulation is not good enough for the increased voltage. Perhaps as a general rule a machine may be speeded until the voltage is double the rated voltage. In selecting a machine, select one whose rated speed is rather low and one in which the mechanical balance of the machine is good.

A Reliance variable speed motor, makes a good variable voltage generator. A 110 volt machine designed for ten to one speed variation will give a ten to one voltage variation when used as a generator. The voltage on a 110 volt machine has been run up to 1000 volts, but it has never been run regularly at that voltage. These machines are made with an armature which is slightly conical and the armature can be pushed endwise in and out of the magnetic field of the poles. As the armature moves out, the air gap increases and thus the flux decreases, causing the voltage to diminish, the speed remaining constant all the time. The field

is excited from an outside 110 volt source. The machine is very satisfactory at 350 to 500 volts.

38. High Potential Generators. Generators are now made to give high voltage for the plate supply of power vacuum tubes. These generators are usually connected directly to the motor. The type and kind of motor used depends on the local power supply. The motor is usually an A.C. motor, 110 or 220 volt. Often a low potential generator is connected to the same shaft of the motor. These generators are used to furnish current for the filaments of the tubes and to supply the field current for the high potential generator.

Figure 18 is a picture of a high potential generator made by the Electric Specialty Co.

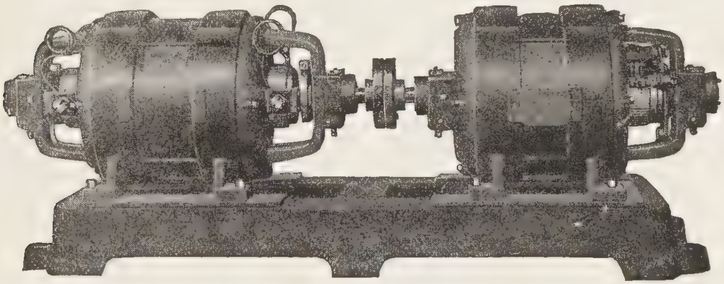


FIGURE 18.

39. Rules for Starting and Running a Dynamo Generator. See that the connections are made so as to let the machine generate.

If the windings are covered so that directions cannot be made out, connect up series or shunt coil alone, and connect the voltmeter to brush terminals. Start the machine slowly and if the connections are made properly the voltmeter should show an increased potential with an increase in speed. If the voltmeter moves up, then drops back to zero, the field connections should be reversed. If the machine is compound, use the shunt coil first, then the series.

Although the machine may be connected up right it may not generate. The fields may not have a residual magnetism. The brushes may not make good contact. The angle of lead may not be right. Some connection may be poor.

After the machine is started the brushes should be adjusted until there is no visible sparking. The brushes are set in the right position, or the angle of lead is right, when the voltmeter shows the maximum voltage. If the machine is a high potential machine the adjustment must be made when the machine is not running. Adjust, start machine, test, stop, adjust and start again.

Before starting, the brushes should be set exactly opposite (on two pole machines). This is best determined by counting segments on the commutator. Determine polarity of poles and armature by means of a compass.

CHAPTER II

BATTERIES

40. Electrolytic Cell. A cell is a device which gives an electromotive force due to chemical action. A number of these devices together is known as a battery. We speak of a battery of 10 cells. A cell of a primary battery consists of two pieces of two substances (electrodes) dipping in an electrolyte contained in a glass, porcelain or rubber jar. The electrolyte is a solution of an acid or of some salt. In all commercial primary cells one of the electrodes is always zinc and the other is usually copper or carbon. The E.M.F. of the cell is due to the fact that the zinc tends to dissolve into the electrolyte. The chemical potential energy of the zinc is changed into electrical energy.

There are a great many different kinds of primary batteries. The two in most general use are the gravity battery and the dry battery.

41. Gravity Cell. The gravity, crowfoot, or blue stone battery gives a constant E.M.F. and does not polarize. It is at its best when used all the time. It consists of a glass jar with a copper electrode made of thin sheet copper at the bottom and a zinc electrode hung at the top of the jar. The zinc is cast so as to resemble a crow's foot. The copper is surrounded with a solution of copper sulphate (blue stone) and the zinc is supposed to be surrounded with a solution of zinc sulphate. The copper sulphate solution is heavier than the zinc sulphate solution. It is assumed that the weight of copper sulphate solution will keep it at the bottom. Or gravity is supposed to keep the two solutions separated. Hence the name gravity cell. The two solutions will mix, due to diffusion, so it is necessary to keep a small current flowing through the cell so as to allow the zinc to dissolve and thus furnish a new supply of zinc sulphate around the zinc. In making up the cell the copper is placed in the bottom and the jar filled about half full of copper sulphate crystals, the zinc is placed in its position and then the jar is filled with water to cover the zinc, and the two terminals are connected or short circuited for a few hours. In this way the zinc

is surrounded with zinc sulphate which is formed by the dissolving of the zinc.

When in good condition the E.M.F. is 1.08 volts, and the internal resistance is usually 2 to 5 ohms. Due to the high internal resistance, the battery is not used where a large current is wanted. The gravity cell is useful for most laboratory measurements where a constant E.M.F. is desired and in places where the external resistance is high, as in telegraph lines. When not in use the battery should be connected to about 50 ohms per cell so that the current through the cell is about .02 ampere. This keeps a fresh supply of zinc sulphate around the zinc. It will be noted that the zinc is being dissolved and the useful life of the cell is being shortened by this process.

When the current flows through the cell the zinc is dissolved into zinc sulphate and the metallic copper is deposited out of the copper sulphate onto the copper electrode. If the current is forced backward through the cell the copper electrode will be dissolved and the zinc electrode should be plated with zinc. Thus it should seem that the battery should be restored by this process. In practice it is found that the zinc deposited will not stick to the zinc electrode and in a short time all the pure zinc sulphate near the zinc will be used up and copper will be deposited onto the zinc. If this restoring process could be carried out we would have a storage battery.

42. Dry Cells. The dry cell is a form of Leclanche, or sal-ammoniac cell. The cell is dry in the sense that the electrolyte will not spill out when turned over. The electrolyte is usually held by some porous substance such as saw dust, sand, or blotting paper. The materials used differ in the different brands of cells. The electrodes consist of a carbon rod and sheet zinc. The sheet zinc is used to make the container for the cell. The carbon rod is surrounded with a mass of ground carbon and oxide of manganese. The manganese serves as a depolarizer as it absorbs the hydrogen gas which is freed at the carbon electrode.

The exact mixture of the electrolyte and details of structure are secrets of the manufacturer.

The process of manufacture differs according to the size and the purpose for which the cell is designed. If one takes an old cell and saws it in two with a hack saw, one can see the general manner of construction.

Dry cells are made in various sizes and shapes. The most common sizes are the No. 6 cell, which means it is 6 inches high, and the small cells used in B batteries.

43. Ammeter Test. It has become the general practice in America to test dry cells by short circuiting them through an ammeter. This in reality is a test for the internal resistance of the cell. Due to this common practice of testing, some manufacturers have decreased the internal resistance of the cell at the expense of useful life of the cell. A cell that will show 30 amperes in short circuit when new may not last as long as one that shows 20 amperes when new.

The E.M.F. of a dry cell is about 1.5 volts when new. As a general thing the E.M.F. of a cell remains near that point throughout its life. Old cells show a high internal resistance. The resistance of the cell may be so high that an ordinary voltmeter will read a few tenths of a volt. When the same cell is measured by a potentiometer it will show as high as 1.3 volts. This means that the internal resistance of the cell is several times the resistance of the voltmeter.

The ammeter method of testing cells is useful in detecting cells that have lost their usefulness as a source of current. For example in the case where dry cells are used as, A batteries or are used to run induction coils. It should be noted that short circuiting a cell shortens its life. The connection should be made for a short time only.

This test is useful to locate cells which have become exhausted or dried out. Connect the cell to a dead-beat ammeter whose internal resistance is .01 ohms. The maximum deflection is taken as the reading. New cells should give 20 to 30 amperes. Used cells will give lower values. When they show as low as 1 or 2 amperes they should be discarded. 1 ampere means that the internal resistance of the cell is about 1.5 ohms. Whether this resistance is detrimental depends upon the resistance of the circuit to which it is connected. When the internal resistance of the battery is equal to the external resistance of the circuit, half of the energy of the battery is used in the battery. If the battery is not working well, replace the cells which show the lowest current—i.e., the highest resistance.

Small dry cells are used in radio work for plate potential or B batteries. Small cells such as originally were used for flash light batteries are used in B batteries.

In these B battery cells, what is wanted is an E.M.F. and little current. Five milliamperes is the usual amount of current through the plate circuit of a single tube. Since the tube and the telephone or coils have high resistance, the resistance of the cell is not so much a factor as in the larger cells. In circuits using several ordinary tubes and one or more power tubes, the current may be as much as 50 milliamperes, and larger B batteries made of larger cells are needed.

The internal resistance of a B battery cell can be measured as in the case of large cells. This is usually not necessary. The essential of a B battery is that its E.M.F. be high and that the cell is not noisy.

44. *Voltmeter Test.* Use a voltmeter to test the E.M.F. of the B battery. If a $22\frac{1}{2}$ volt cell reads from 15 to $22\frac{1}{2}$ volts it may be considered to be in fair condition. Connect a high resistance telephone head-set across the battery, care being taken to have good connections. There should be no sound in the telephone except the click made when the connection is made and broken. The loudness of this click on making contact can be taken as an indication of voltage of the battery. If a new battery is at hand, a comparison of the click made by the new battery to that of the old will give an indication of the E.M.F. of the old battery.

If there is a rattle or popping in the telephone when the connections are good the battery is noisy and the poor cell or cells must be removed. This popping sound is caused by a poor connection which makes the current intermittent. The trouble may be a poorly soldered joint or it may be inside the cell, due probably to the material of the cell becoming dry and making the conduction uncertain. Measure each individual cell or flash light battery. The cell whose E.M.F. as measured with the voltmeter, is 25% or less than the normal voltage, is usually the one which causes the noise in the battery. Remove or short circuit this cell or flash battery. With the modern B battery this is impracticable. If the sealing wax is removed with care the bad cell can be located, but from a financial point of view this will not pay. Discard the battery and get a new one.

45. *Storage Batteries.* The lead storage battery consists of two sets of grids or plates separated by spreaders, generally of wood, placed in a sulphuric acid solution. The positive grid is pasted with lead peroxide and the negative grid is of lead in a finely divided state, or spongy lead. When discharging, the chemical action is such as to tend to make both plates of the same chemical composition. When the cell is charged the two grids are restored to the original chemical condition. It is not electricity which is stored. It is energy which is stored in a chemical Form. Figure 1 is a picture of a storage battery in a glass case.

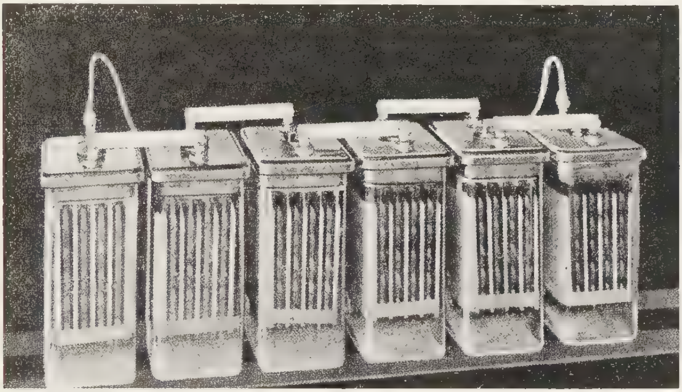


FIGURE 1.

The E.M.F. of a lead storage cell is 2.3 volts when fully charged, and 1.8 volts when discharged. The average E.M.F. is 2 volts. The internal resistance is very low. The storage battery is used where relatively high currents are wanted through small external resistances.

The storage battery is at its best when it is used every day,—discharged and charged several times each week. If a storage cell which has been discharged to 1.8 volts is charged, the E.M.F. rises rapidly to about 2 volts and remains constant until it is nearly fully charged and then rises rapidly to 2.5 volts. Thus a voltmeter reading will tell when the cell is fully charged or discharged, but will not tell the state of charge at intermediate times.

The density of the sulphuric acid increases continuously during charge and decreases during discharge. It is customary to use a

hydrometer to measure the density of the acid and thus determine the state of charge of the cell. Thus in a cell whose acid density at full charge is 1.285 and at discharge is 1.17 is about one-half charged when the hydrometer reads 1.225.

The density of the acid varies in different makes of cells. Some cells have a density as low as 1.210, but the tendency in the past years has been to raise the density of the acid, some makers using as high as 1.300 for the density of the acid when the cell is fully charged. It will be seen that the hydrometer does not tell the state of charge of a cell unless the type or make of cell is known to the tester. The usual variation of density between discharge and full charge is about .110, or from 1.100 to 1.210 or 1.170 to 1.285.

A storage battery should be charged at the normal rate as indicated on the name plate of the battery until hydrogen gas is liberated freely in the electrolyte, and then the amperage should be cut to about one-third of the original and then charged until the cell gases freely. Measure the density of the acid under this condition and you have the full charge density.

The addition of strong acid will not charge the cell.

A storage battery should never be allowed to stand for any length of time while discharged. A cell not in use should be charged once every two weeks.

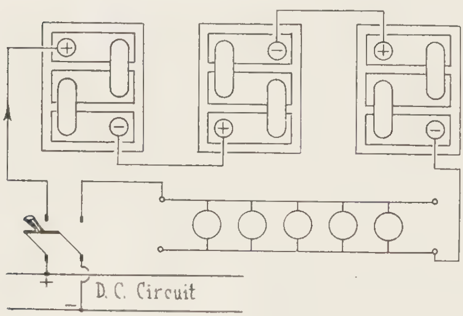


FIGURE 2.

46. To Charge a Storage Battery. Use a D.C. circuit or a rectifier on A.C. circuit. The E.M.F. of the charging circuit must be greater than that of the battery at full charge. A regulating resistance must be placed in series with the battery. For small batteries charged from D.C. lighting circuits a bank of lamps makes a good regulating resistance. Figure 2 shows the connection to a D.C. lighting circuit in which lamps are used as the regulating resistance.

To determine the polarity of the terminals of the charging circuit, connect the positive of the circuit to the positive of the battery and the negative to negative, the cells being connected in series, of course.

When the battery to be charged is 6 volts and the charging circuit is 110 or 32 volts, the polarity can be determined by connecting a single lamp in series and closing the switch. Note the brightness of the lamp. Reverse the battery and connect again. The proper connection is when the lamp is the dimmest.

Another method is to connect two wires to the charging circuit, a lamp or other suitable resistance being placed in series, and dip the ends of the copper wires into a glass of water, Figure 3. Bubbles of gas will appear at the wire connected to the negative terminal of the charging circuit. The water will become blue at the wire connected to the positive terminal of the charging circuit. A voltmeter with wet paper resistance, or an ammeter with high resistances in series can be used to determine the polarity of the circuit.

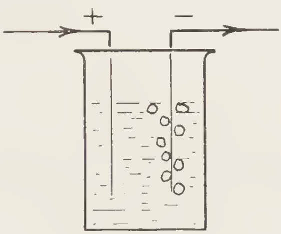


FIGURE 3.

When charging a battery, regulate the current by means of the lamps or resistance until the current is the value recommended on the name plate on the battery. The battery may be charged at a lower rate than the rate recommended, but never at a higher rate. It will take longer to charge at the low rate than at the high rate. The charging rate of a battery should not be so great that the temperature of the cell rises appreciably. For a "Ford" battery the charging rate is from 5 to 10 amperes. The battery is fully charged when it gases freely with a small ampere rate of charge. The plates should be evenly covered with the solution. Fill with pure distilled water to the proper depth. Any impurity such as iron is detrimental to the cell. Keep the distilled water and acid in covered glass containers. Use a glass rod as a stirrer. Never let the water or acid come in contact with wood. Sometimes one sees the statement that the water of a certain city is so pure that garages use this water instead of distilled water for refilling batteries. This may be good advertising for the city but is very

poor advertising for the garages. If the old flivver will still puff drive on.

If a discharged cell whose E.M.F. is 1.8 volts is connected to a charging circuit and charged at the rate recommended by the name plate, the voltage and hydrometer reading as read from hour to hour until the cell is gassing freely, will be shown by the curve marked density as in Figure 4. The voltage rises rapidly and remains almost constant until fully charged and then rapidly rises as indicated. The density changes gradually until fully charged.

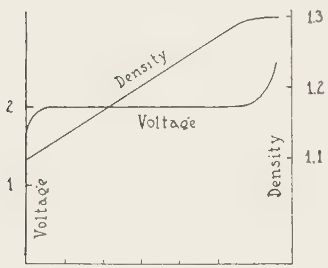


FIGURE 4.

If several cells are to be charged at the same time, connect the cells in series, i.e., positive of one to the negative of the next, until all the cells are connected. Figure 2. The sum of the E.M.F.'s of all the cells must not be more than the E.M.F. of the charging circuit. On a 110 volt circuit the E.M.F. of the series group should not be more than 100 volts. On a 32 volt circuit it should not be more than 25 volts. The batteries as connected are now placed on the charging circuit with the resistance in series and the current regulated. The charging rate must not be more than that of the smallest battery connected.

Very low or small charging rates tend to spoil the battery. Trickle chargers, in which the battery is charged continuously at a very slow rate, shortens the life of the battery.

An automatic device to turn the cell onto the charging circuit when nearly discharged, and then charge at a relatively high rate and then disconnect when fully charged, is ideal but all automatic devices must be watched.

47. Connection of Cells. Cells are connected in series, in multiple, or in multiple series. In series connection the positive terminal of one cell is connected to the negative terminal of the next, the positive terminal of cell No. 2 is connected to the negative of cell No. 3, etc., Figure 5.

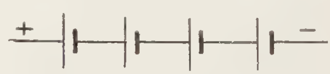


FIGURE 5.

The E.M.F. of a number of cells in series is the sum of the separate cells. Or $E = ne$ if all the n cells are alike. The resistance is the sum of the separate resistances, or $R = nr$.

In connecting in multiple, or parallel connection, all the positive terminals are connected together and all the negative terminals are connected together, Figure 6. The E.M.F. is the same as that of one cell, and the resistance is the resistance of one cell divided by the number of cells, $R = r/n$. Unlike cells should never be connected in multiple. In multiple series a certain number of cells, m, are connected in multiple. This is repeated until we have s groups of the multiple connections and these groups are connected in series. The total number of cells then will be nms, Figure 7.

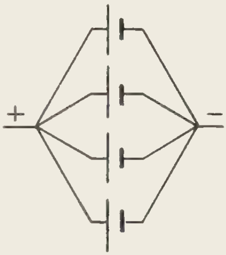


Figure 6.

The E.M.F. of the battery will be s times the E.M.F. of one cell. The resistance of the battery, $R = rs/m$. The same thing can be obtained by connecting the cells into m groups of s cells in series in each group and then connecting the m groups in multiple, Figure 8.

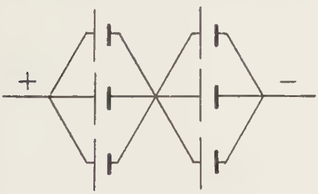


Figure 7.

48. Combination of Cells for Maximum Current. If we have N cells all alike and we wish to connect them in multiple-series in such a manner to get the maximum current from the battery through an external resistance R, we can proceed as follows: Let us connect the cells into m groups, each group having s cells in series. Then connect these m groups in multiple. Then the number of cells $N = ms$. The E.M.F. is se where e, is the E.M.F. of a single cell.

The resistance of the battery is sr/m where r is the resistance of a single cell. Then the current

$$I = se/(sr/m + R) = e/(r/m + R/s).$$

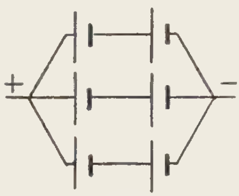


Figure 8.

The current will be the greatest when the denominator is the least. The product of these two quantities is $rR/ms = rR/N$ all these terms being constant, the product is constant. If the product of two quantities is constant the sum of the two is least when they are equal. Then $r/m = R/s$ or $sr/m = R$. But sr/m is the internal resistance of the battery, therefore the current is the greatest when the cells are connected so as to make the internal resistance equal to the external.

Since the power delivered to the load, whose resistance is R, is I^2R, the power is the greatest when the internal and external resistances are equal. It can also be shown by means of calculus that the power delivered by a battery of E.M.F., E, and resistance, r, to an external resistance, R, is a maximum when R is made equal to the resistance of the battery. This paragraph is inserted because it has a bearing on the matching of impedance or loads. In general, for quality of tone the output and the input of the amplifier and loud speaker must be matched. This will be discussed in Chapter 28.

CHAPTER III

MEASUREMENT OF RESISTANCE

49. *General Statements.* There are several methods of measuring resistance which are given in any good physics laboratory manual. Two methods will be described here as being the most important for use in radio measurements.

50. *Ammeter-Voltmeter Method.* This consists of measuring the current through the resistance with an ammeter and the Pd around the resistance with a voltmeter, and solving for the resistance by means of Ohm's Law $R=Pd/I$. This method is useful in measuring resistance which will carry relatively large currents and have resistances from about 0.1 ohm to 1000 ohms. The resistance of lamps, large rheostats, armatures, and fields of motors and generators can usually be conveniently measured by means of this method. Small coils such as coils in ordinary resistance boxes, should not be measured by this method, as there is danger of sending too much current through the coils and burning them out.

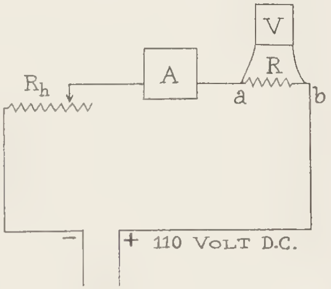


FIGURE 1.

The assumptions made in these measurements are that the ammeter has zero resistance and that the current through the voltmeter is zero. These assumptions are only approximately true. In measuring a small resistance such as the resistance of an armature of a generator, the connection should be made as in Figure 1. The source of current is a D.C. 110 volt switch or a storage battery capable of delivering several amperes of current. R_h is a regulating rheostat or bank of lamps by means of which the value of the current is regulated. a and b are the points of contact of the voltmeter around the armature R. In this case the current through the ammeter is the current through the armature which is several

amperes plus the current through the voltmeter which is a few milliamperes. The voltmeter current can in this case be disregarded. In this case, $R = Pd/I$ is the resistance of the armature. If the connection was made as in Figure 2, then $R = Pd/I$, resistance of armature plus the resistance of the ammeter, and in certain cases the resistance of the ammeter will be equal to or greater than the resistance R. If the resistance is great, connect as in Figure 2. In this case the resistance R is great and an addition or error of a few hundredths ohms can be neglected. If connected as in Figure 1 the current through the voltmeter may be much greater than the current through the resistance R. Milliammeters and millivoltmeters can be used instead of ammeters, but the errors due to the resistance of the milliammeter and the current through the millivoltmeter is liable to be great.

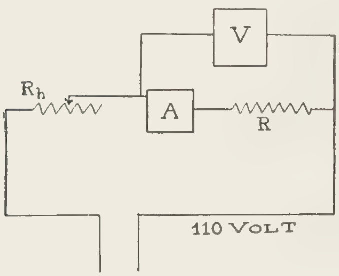


FIGURE 2.

Be sure the current is not greater than the maximum range of the ammeter and that the Pd is not greater than the maximum range of the voltmeter.

51. Wheatstone Bridges. The Wheatstone bridge consists of four resistances. The value of one of these resistances is known. The ratio of the resistances of two others is known. The fourth is the unknown, or the resistance to be measured. These four resistances are connected together to form a closed circuit. Diagrammatically the resistances are connected to form a diamond or parallelogram as in Figure 3. R is the adjustable known. R_1 and R_2 are the ratio arms. The ratio of R_1 to R_2 is known. X is the unknown. A galvanometer is connected across one diagonal of the diamond and a battery across the other

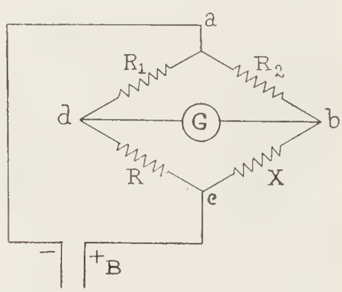


FIGURE 3.

diagonal. The resistance R is changed until there is no current through the galvanometer, then the potential of b is equal to the potential of d. Then $Pd_{ab}=Pd_{ad}$ and $Pd_{bc}=Pd_{dc}$ and $I_1=I_R$ and $I_2=I_X$. Since $Pd_{ab}=I_2R_2, Pd_{ad}=I_1R_1$ and $Pd_{dc}=I_RR$ and $Pd_{bc}=I_XX$, then $X=R_2/R_1\ R$.

52. Slide Wire Bridge. The bridge is of two common forms—the slide-wire bridge and the box bridge. The slide wire bridge consists of a No. 20 manganin or German silver-wire usually one meter long, stretched on a board and soldered to two heavy bars of copper or brass. Figure 4. This heavy bar is extended along the back of the board usually with four openings with binding posts so as to connect resistances. Two of these openings for simple measurements are closed with heavy conductors. The resistances of these heavy bars and straps are considered to be zero.

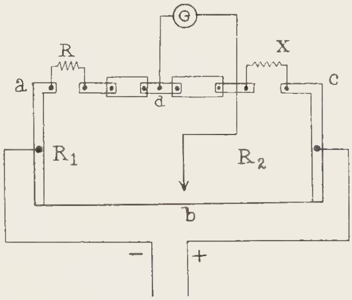


FIGURE 4.

It will be seen that the resistances R_1 and R_2 are that of sections of the wire. Since the resistance of the wire is uniform, then l_1 and l_2, lengths, can be substituted for R_1 and R_2. In this bridge the known resistance R can be fixed and the ratio of R_1 to R_2 can be changed until the bridge is balanced. For exact measurements it is best to adjust the known resistance R so that the sliding point b is near the center of the wire. Slide-wire bridges can be constructed very cheaply and still give fair results.

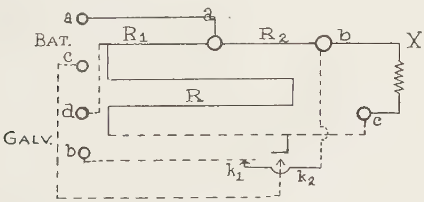


FIGURE 5.

53. Box Bridges. The box bridge consists of three resistance boxes and the unknown. These three resistances are usually placed in the same box and marked terminals and keys placed conveniently. In all bridge work two break keys should be used, one in the battery and one in the galvanometer circuit. Figure 5 is a diagram of one form of box bridge. The letters on

the diagram correspond to those in diagram, Figure 3. In any bridge work the bridge should be studied by diagramming it and determining the points which correspond to the diamond, Figure 3. Pieces of paper with the letters can be fastened to the box until one is able to see the particular bridge in the "diamond form."

All box bridges are alike in principle but their outward form may be very different. Figure 6 shows a modern box bridge.

In using a box bridge, connect the unknown in and select some value for the ratio $R_1 = R_2$. Let $R = 0$. Press the battery key and then the galvanometer key and note the direction of deflection.

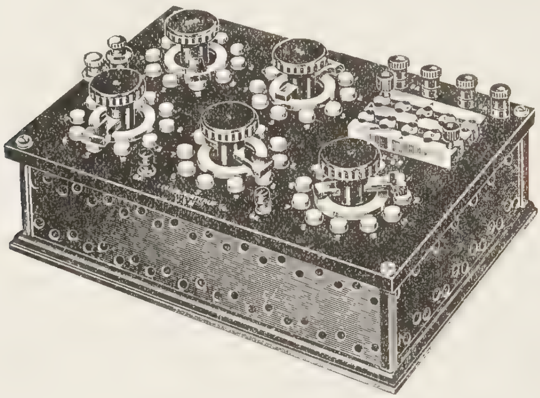


FIGURE 6.

This is the direction of deflection when R is too small. Select some large value of R. The direction of deflection will be in the opposite direction if R is greater than X. Then X lies between zero and the large value of R. Make R about one-half of the large value, then from the direction of deflection it is easy to determine whether the value of X is greater or less than the last value. Make R some other value near the intermediate value, noting deflection. By approximating closer and closer, in a short time approximate value of X can be determined.

After the approximate value has been determined, the ratio of R_1/R_2 may be changed so as to obtain more exact measurement.

If the resistance to be measured is a coil containing much inductance, care must be taken not to close or open the battery key while the galvanometer key is closed, otherwise there will be a

momentary deflection or kick of the galvanometer even if the bridge is balanced.

54. High Resistances. High resistances can be measured and tested if one has a box bridge which has large resistances. Perhaps a better way is to use a comparison method using a sensitive galvanometer and compare the resistance with a 10000 ohm coil.

Grid leak resistances should be tested for noise. Often resistances made of carbon or by the sputtering method conduct intermittently as if there were a small spark gap in the circuit. This causes noise and a set in which this is introduced will be noisy. This can be tested by placing the resistance in series with a B battery and a head set. The resistance can also be tested by placing it in the input circuit of an amplifier. This amplifier can be any sort of an amplifier resistance, impedance or audio coil amplifier.

Figure 7 gives a diagram of the first stage, the one into which the resistance is inserted. A milliammeter is inserted in series with the resistance. The current should be adjusted to the normal value, the current which flows in the resistance when in use.

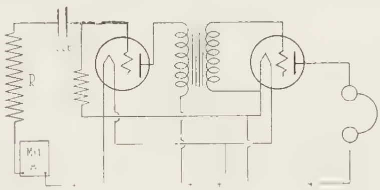


FIGURE 7.

The amplifier should be tested for noise before the resistance is inserted.

55. Use of Alternating Current in Resistance Measurement. When making certain measurements there are often troublesome E.M.F.'s in the circuit, such as thermal junction effects or electrolytic polarization, which make it hard to get exact balances of the bridge.

Thermal junction effects can be practically eliminated by using D.C. batteries and making measurements and then reversing the battery and taking another balance. The mean of the two results can be used as the right result.

With electrolytic resistances the E.M.F.'s build up and oppose the direction of the currents after they have continued for some time. If A.C. is substituted for the battery the time is short and these E.M.F.'s are inappreciable and the rapid reversing elimi-

nates the effects. If a telephone is used in place of the galvanometer, bridges can often be used with A.C.

The bridge and all resistances must be non-inductive resistances Figure 8 shows a shielded resistance box, and the inside of the box. Any inductance introduces an impedance which can not be balanced out with the ordinary bridge. The resistance of coils can

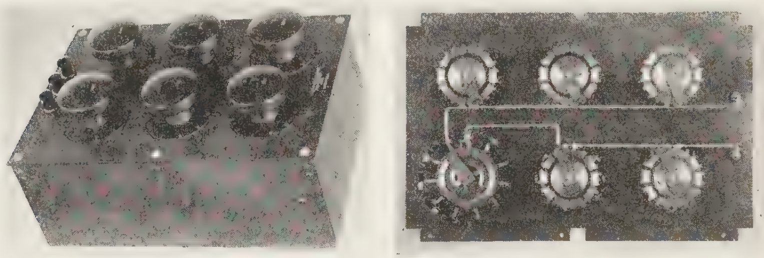


FIGURE 8.

not be measured with A.C. unless they are non-inductively wound. Ordinary resistance boxes are non-inductively wound by unreeling the proper amount of wire, doubling the wire and winding it on a spool so that the current flows around the spool in both directions the same number of times. These spools are non-inductively wound, but since the two halves of the wire are side by side the

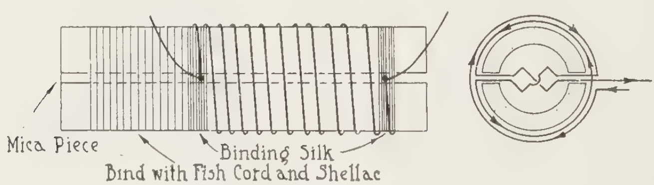


FIGURE 9.

capacity from wire to wire is rather large. This capacity introduces an impedance which may effect the measurements at times. Resistance boxes intended for high frequency measurements have coils which are wound in a manner to eliminate both inductance and capacity. Figure 9 shows the method of winding a coil to eliminate capacity and inductance.

CHAPTER IV

ALTERNATING CURRENT

56. Introduction. Radio is a special application of alternating current. In all radio circuits we have condensers, and coils. Coils have inductance, and resistance. A radio circuit consists of resistance, inductance, and capacity. The frequency of radio current is very high, the order of one million cycles or more. Radio current is alternating current of high frequency. The current used in most cities for house lighting is alternating current whose frequency is 60 cycles per second. The only difference between radio current and the current in the incandescent lamp is in the frequency.

When we have resistance, inductance and capacity in a circuit the equation for the current is

$$I=\frac{E}{\sqrt{R^2+(L\omega-1/C\omega)^2}}$$

where I = current, E = electro-motive-force, L = inductance, C = capacity, and $\omega=2\pi n$, where n is the frequency.

A small coil has small inductance but when the frequency is high the term $L\omega$ becomes very large and the current is impeded and becomes very small, even if the resistance, R, is small.

By taking a condenser of proper size the term $1/C\omega$ can be made equal to $L\omega$, the bracketed term in the impedance becomes zero and we have $I=E/R$. And if the resistance is small the current will be large. Such a circuit is known as a resonant circuit, or tuned circuit. Radio is the study of tuned or resonant alternating circuits and currents.

In order to understand resonant circuits it is necessary to have some idea of alternating currents. In a text of this kind it is not expected to give a complete treatise on alternating current. It is hoped to treat or mention the essential points only. For more detail, a good text on this subject should be consulted.

57. Generation of Alternating Currents. When a coil of wire is rotated at a constant rate in a constant field the rate of cutting

lines of force is proportional to the sine of the angle, sin θ, where θ is the angle the plane of the coil makes with the position it occupied when the plane of the coil was perpendicular to the field, Figure 1. The E.M.F. which is proportional to the rate of cutting lines of force will then be proportional to sine θ or $e=E \sin \theta$, when e is the E.M.F. at any time, t, and E is the maximum E.M.F. Since, angle is equal to angular velocity times time, or $\theta=\omega t$, where ω is the angular velocity or the number of radians the coil turns through per second, we have $\omega=2\pi n$ and $\theta=2\pi nt$ and $e=E \sin \omega t = E \sin 2\pi nt$, where n is the number of revolutions of the coil per second. Since there is a complete alternation in one revolution of the coil, n is the number of alternations per second, or the number of cycles. Thus we speak of 60 cycle current. In a 4-pole machine there are two cycles per revolution and the frequency is revolutions per second times the number of pairs of poles. An A.C. generator is a machine which will give an E.M.F. whose equation is $e=E \sin wt$.

FIGURE 1.

58. Coils in Alternating Circuits. If a coil of wire is connected to an alternating E.M.F. Fig. 2 there will be an E.M.F. set up in the coil which is proportional to the rate of change of the magnetic field of the coil.

Then Ohm's law, which for steady current is $E=IR$, becomes $E=IR + dN/dt$, where dN/dt is the E.M.F. due to the change of the field N.*

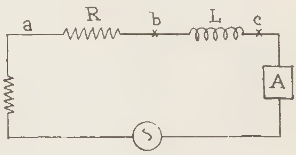


FIGURE 2.

The coefficient of self-induction of the coil, L, is the E.M.F. of the coil when the current changes at the rate of one ampere per second. Then $dN/dt=L\,dI/dt$ and since $e=E \sin \omega t$, we have $E \sin \omega t = L\,dI/dt+IR$. The solution of this differential equation gives,

$$I=\frac{E}{\sqrt{R^2+L^2\omega^2}} \sin(\omega t-\tan^{-1} L\omega/R),$$

* dN/dt is read the rate of change of the flux, N, with respect to the time, t. It is the mathematical way of saying the number of lines of force cut per second. $L\,dI/dt$ reads the inductance, L, times the rate of change of current, I.

I being the value of the current at any time t after the switch has been closed for some time, which is long compared to one cycle.

59. *Maximum Current.* The maximum value of I will be, at the time t, such that $\sin(\omega t - \tan^{-1} L\omega/R) = \text{unity}$.

Then

$$I_{\text{max.}} = \frac{E_{\text{max.}}}{\sqrt{R^2+L^2\omega^2}}$$

Since $e = E_{\text{max}} \sin \omega t$, $e = E$, at such a time that $\sin \omega t = \text{unity}$, and I will equal I_{max} at some later time such that $\sin(\omega t - \tan^{-1} L\omega/R) = \text{unity}$. Or the current is said to lag behind the E.M.F. by the phase angle, $\theta = \tan^{-1} L\omega/R$.

60. *Virtual Current.* In practice we do not measure the maximum current or voltage, or yet the average current or voltage, but the virtual current or voltage which is the root mean square current or voltage. If Figure 3 represents a single cycle of current, then the virtual current is obtained by drawing vertical lines at regular intervals every five degrees, say. Measure the length of each line, square this value, and take the sum of all the squares and then divide by 36, the number of lines, and we have the average or mean square of the current for one-half cycle. Extract the square root of this mean and we have the root mean square. The root mean square of the second half of the cycle will be the same as that of the first half-cycle. When this is done the virtual current is found to be

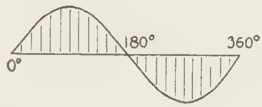


FIGURE 3.

$$I_{\text{virt.}} = \frac{I_{\text{max.}}}{\sqrt{2}} = \frac{1}{2}\sqrt{2}I_{\text{max.}} \text{ or } \frac{I_{\text{max.}}}{1.414} = .707 I_{\text{max.}}.$$

In like manner

$$\text{Virtual } E = \frac{E_{\text{max.}}}{1.41} = .707\ E_{\text{max.}}.$$

Since

$$.707\ I_{\text{max.}} = \frac{.707\ E_{\text{max.}}}{\sqrt{R^2+L^2\omega^2}}$$

$$I_{\text{virt.}} = \frac{E_{\text{virt.}}}{\sqrt{R^2+L^2\omega^2}}$$

R is the resistance and $L\omega$ is called the reactance. $\sqrt{R^2+L^2\omega^2}$ is called the impedance.

The heating effect of a current flowing through a resistance is proportional to the square of the current or I^2. A virtual current of one ampere alternating current is that current which will produce the same heating effect as one ampere of direct current. The heating effect may be measured by the brightness of the wire as in an incandescent lamp or by the change of the length of the wire as in a hot wire ammeter.

61. A.C. Instruments Read Virtual Values. All alternating ammeters and voltmeters read the virtual current and virtual voltage. Thus in a hot wire ammeter the deflection is proportional to the mean heating effect, I^2R. If one ampere deflects 1 scale division, 2 amperes will deflect it 4 scale divisions, and 3 amperes will deflect 9 divisions, etc. The graduation is 1, 2, 3, instead of 1, 4, 9, or the marking on the scale is such as to give the square root of the mean deflection. Figure 4 illustrates this.

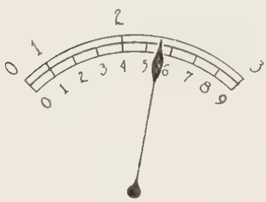


FIGURE 4.

62. Vector Diagrams. The equation

$$I=\frac{E}{\sqrt{R^2+L^2\omega^2}}$$

may be written $E^2=I^2R^2+I^2L^2\omega^2$.

Thus E^2, the E.M.F. of the A.C. generator is equal to I^2R^2 the square of the IR drop, plus $I^2L^2\omega^2$, the E.M.F. due to the inductance of the coil. The square of one term equaling the sum of the squares of two others suggests a right angle triangle. The square of the hypotenuse equals the sum of the squares of the other two sides. If in Figure 5 IR is the base, then E, is the hypotenuse and $IL\omega$ is the height of the right angle triangle. θ, the angle between the base and hypotenuse, is the phase angle, $\theta=\tan^{-1} IL\omega/IR$, which we have said was the angle the current lagged behind the E.M.F., E.

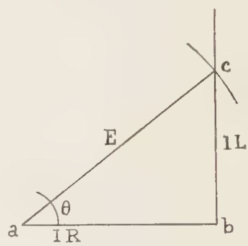


FIGURE 5.

Since IR is the Pd or E.M.F. due to the resistance, and $IL\omega$ the E.M.F. due to the inductance, then E is not equal to the algebraic sum of the other two, but the vector sum of the other two. Thus E.M.F.'s in alternating currents must be added vectorally in the same manner as forces, velocities, or distances. The E, the hypotenuse in Figure 5, is the vector sum of the other two E.M.F.'s, or of the other two sides of the triangle.

In Figure 2, all the resistance is represented as being between ab, and all the inductance between bc. Then a, b, c, is the right triangle of Figure 5. A voltmeter connected to ac gives E, when connected between ab gives the IR drop, and when connected between bc gives the E.M.F. due to inductance. In general, the resistance, R, is distributed throughout the circuit and the inductance, L, is also distributed so it is impossible to locate the point, b.

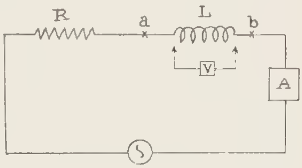


FIGURE 6.

The resistance of the coil or circuit can be measured by means of D.C. current. Then IR for any A.C. current, I, can be calculated. Then E, the A.C. voltage between ab, Figure 6, can be measured with an A.C. voltmeter and the value of I measured with an A.C. ammeter at the same time. Then we have two sides, the base and hypotenuse of a right angle triangle to construct the triangle, Figure 5, and thus determine the height, which is $IL\omega$. Knowing I and ω, L can be calculated.

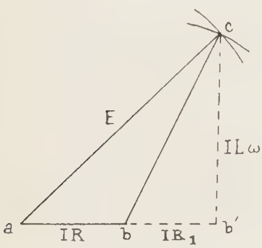


FIGURE 7.

63. *Resistances and Coils in Series.* If we place a resistance such as an incandescent lamp in series with a coil, which can be represented by Figure 2, the vector diagram of the coil is a right angle triangle $bb'c$, Figure 7. The IR drop of the coil is bb'. The current is in phase with the IR drop and is represented as being along the base of the triangle. The phase angle of the coil is the angle cbb'. The reactance of the coil is $L\omega$. The E.M.F. due to this reactance is the perpendicular cb'. The impedance of the coil is $\sqrt{R^2+(L\omega)^2}$. The added lamp increases the resistance, but since a lamp is non-inductive for low

frequency it adds nothing to the inductance. Then in the vector diagram the IR drop due to this resistance is represented by ab which is in the same straight line as bb'. The total IR drop is ab'. The total inductance has not been changed, then the vector diagram of the circuit is the right angle triangle $ab'c$. But b' is some indefinite point in the coil. The points abc are the terminals of the lamp and coil. Then in the vector diagram the voltage around the the lamp is ab, the voltage around the coil is bc, and the total voltage is ac. Thus the vector diagram of the circuit is the obtuse triangle abc and the voltage due to the inductance is the perpendicular let fall from c to the line ab produced.

Thus: if a voltmeter is placed first around the lamp and then around the coil and last around the coil and lamp together, the three readings can be used to construct the triangle abc making the line ab horizontal. The construction is, given the three sides of a triangle to construct the triangle.

To calculate the inductance, drop the perpendicular cb' and measure its length and set equal to $IL\omega$ and solve for L. The current I having been measured with an ammeter and ω being known from the frequency, $\omega = 2\pi n$.

This is known as the three voltmeter method of measuring inductance. (Experimental Radio, p. 15)

The phase angle of the circuit is the angle cab, while the phase angle of the coil is cbb'. It will be seen that the addition of resistance diminishes the size of the phase angle.

FIGURE 8.

If a number of coils and resistances, Figure 8, are placed in series, the total resistance is the sum of the resistances and the sum of the separate inductances is the total inductance.

In proving that the resistance of two or more resistances is equal to the sum of the separate resistances, when using D.C. we start with the proposition that the total drop of potential through the resistances is equal to the sum of the separate potential drops, and that the current is the same in all coils. With coils and resistances in series with alternating current, the same is true except we take the vector sum of the potentials instead of the algebraic sum. Figure 9. "Experimental Radio" Experiment 16.

64. Coils and Resistances in Parallel. In this case the potential across each coil is the same and the current is the vector sum of the separate currents. The method of proof is very much as that where we have resistances in parallel with D. C. The application of the vector addition of currents to the case does not give a simple statement like the reciprocal law of resistances in parallel.

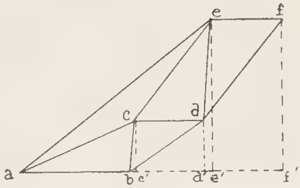


FIGURE 9.

If a resistance, R, and an inductance, L, are connected in parallel, Figure 10, the total current is equal to the vector sum of the separate currents, or we have the closed triangle aF_1F_{12}, Figure 11.

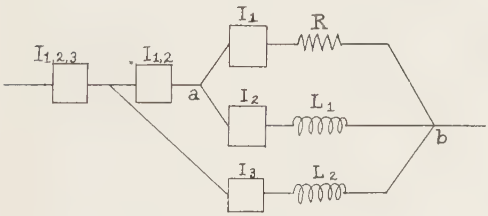


FIGURE 10.

The E.M.F. in this case is drawn vertical, and the current through the resistance, R is in phase with the E.M.F. Completing the parallelogram, we have the direction or phase of the current, I_2 as aF_2. The IR drop ac_2 is in phase with the current, I_2, and must make a right angled triangle with the E.M.F., ab. The semicircle is drawn on ab as a diameter for convenience in constructing the right angled triangles. The angle bac_{12} gives the phase angle of the resultant current I_{12}. Using the same reasoning we have the line ac_{12} as the IR drop and the line bc_{12} as the resultant IL of the resultant circuit, from which the resistance and the inductance can be computed. Thus a resistance and a coil in parallel are equivalent to, or can be replaced with, a resistance and a coil of such values as to give the vector diagram $ac_{12}b$.

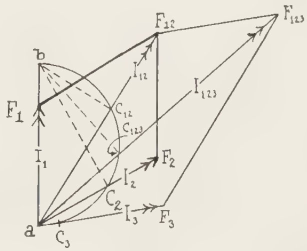


FIGURE 11.

The third coil can be combined in the same general manner using the resultant current, I_{12}, and the current, I_3. The principle is the same as that used with three forces; two are combined vectorally and then the third is combined with the resultant of the first two.

The three circuits are the same as a coil having resistance and inductance such as to give the current I_{123} with a phase angle baI_{123}.

Although a general statement of the values is not simple to make, it can be said that any number of coils and resistances in parallel are equivalent to a resistance and an inductance in series.

65. Circuits Containing Capacity. If we have a circuit with a resistance and an inductance and a capacity in series, then our differential equations become $E \sin \omega t = IR + L(dI/dt) + \int I dt/C$ where C is the capacity of the condenser. The solution of this is

$$I = \frac{E}{\sqrt{R^2 + \left(L\omega - \frac{1}{C\omega}\right)^2}} \sin\left(\omega t - \tan^{-1}\left(L\omega - \frac{1}{C\omega}\right)\right).$$

If L is zero, then

$$I = \frac{E}{\sqrt{R^2 + \left(\frac{1}{C\omega}\right)^2}} \sin\left(\omega t + \tan^{-1}\frac{1}{C\omega}\right).$$

Our reactance in this case is $1/C\omega$, and our phase angle is positive and the current is said to lead the E.M.F. It will be remembered that it lagged in the case of resistance and inductance.

As in the case before, we can write the equation as $I = E\sqrt{R^2 + (X)^2}$ where X is the reactance, I the virtual current, and E virtual E.M.F.

If $L = 0$ and $R = 0$, we have $I = E\sqrt{(1/C\omega)^2} = CE\omega$. This equation will apply to a good condenser placed in an alternating circuit, the resistance of a good condenser being very small.

In this case the current in the condenser makes an angle which is practically ninety degrees with the E.M.F. If the angle is ninety degrees, then the current is wattless current and the condenser consumes no energy. This is true, since the resistance is zero and no energy is used in a circuit in which there is no

resistance. There being no resistance there is no I^2R loss and no heat will appear. If the condenser gets hot then there is resistance in the condenser and the phase angle is less than ninety degrees.

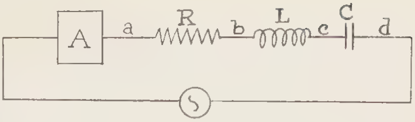


FIGURE 12.

66. Vector Diagrams with Condensers. The vector diagrams with condensers and resistances are made in the same way as when resistances and inductances are connected together, the reactance being $1/C\omega$ instead of $L\omega$. The current is said to lead the E.M.F. instead of lagging behind the E.M.F. as in the case of coils.

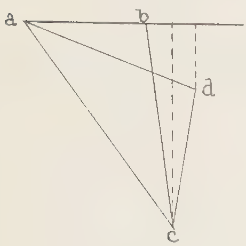


FIGURE 13.

67. Circuits with Resistance, Inductance and Capacity in Series. If the resistance, inductance and capacity are connected as in Figure 12, the vector triangle *abc* for the resistance and inductance will be the same as when the circuit contains only resistance and inductance except that now since we have both negative angles and positive angles to deal with we will turn the triangle over, placing the angle, θ, below instead of above the horizontal line, *ab*, as we did in Figure 9. The point, *d*, is determined by knowing the voltages, *ad*, *bd*, and *cd*. Using arcs proportional to the voltages we have the lines *ab*, *bd*, and *cd* meeting at the point *d*. The point, *d*, may be below the line *ab*, as in Figure 13, or it may be above the line *ab* as in Figure 14. In Figure 13 the resultant angle is negative, or the current lags behind the E.M.F. by the angle *bad*; or the resultant angle may be positive as in Figure 14, and the phase angle, *bad* positive and the current leads the E.M.F. The conditions in Figure 14 can be changed into the conditions of Figure 13 by either increasing the inductance and thus making the lag greater, or by increasing the capacity and making the lead less. The dotted line

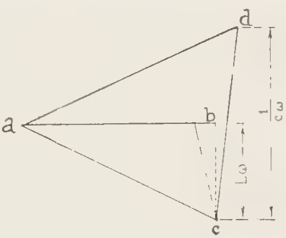


FIGURE 14.

db represents the quantity $(1/C\omega - L\omega)$ and may be either positive or negative. When $(1/C\omega - L\omega)$ is zero, then the point *d* lies on the line *ab* produced and the phase angle is zero. Then the current is in phase with the E.M.F.

68. Series Resonance. In our equation,

$$I = \frac{E}{\sqrt{R^2 + (L\omega - 1/C\omega)^2}}.$$

Since $(L\omega - 1/C\omega) = 0$, we have $I = E/R$.

Figure 15 is the vector diagram of a lamp, an inductance and a ten microfarad condenser in series and adjusted for resonance with 60 cycle A.C. The voltages given in the diagram are the actual measured voltages.

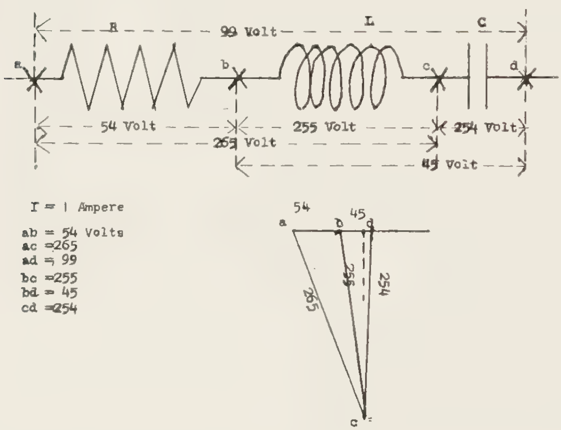


FIGURE 15.

It may be well to call attention to the fact that the three voltages measured from left to right are 54, 255, and 254 volts, and the measured voltage across all three is 99 volts. In other words, 54 plus 255 plus 254 is equal to 99, vector addition. This is shown in the vector diagram. A circuit so adjusted to make the phase angle zero is said to be adjusted to resonance. Since the impedance of the circuit becomes the resistance, *R*, the current is a maximum. An ammeter in the circuit will show the condition of resonance. The adjustment can be made by gradually changing either the inductance, the capacity, or the frequency until the current as shown in the ammeter is the largest value possible with the given resistance.

69. The Maximum Current Depends upon the Resistance. If the resistance, *R*, is diminished, the current will increase, since the

maximum current is $I = E/R$. If in the circuit of Figure 15 the resistance had been decreased until the current had been two amperes instead of one ampere, the potential across the inductance and condenser would have been doubled or near 500 volts. In that case the vector sum of voltages whose algebraic sum is about 1000 volts would have been 99 volts.

This circuit is the fundamental circuit of radio. Radio is a special case of resonance with alternating current. A good understanding of the cause of the increased current and the increased potential across the condenser and coil is imperative to a full understanding of radio circuits.

70. Parallel Resonance. We have given the vector diagram, Figure 11, for resistance and inductance in parallel. The theory for resistance and capacity in parallel is the same except one must remember that capacity makes the current lead the E.M.F., and that the reactance for a condenser is $1/C\omega$ instead of $L\omega$. There is one case of special interest—the case of a coil and a condenser in parallel. As a usual thing it is necessary to place a resistance in the circuit to get a starting point. The phase angle of a coil is uncertain but in a resistance the current is in phase with the E.M.F. In the case of the condenser we can assume that the current leads the E.M.F. ninety degrees and then using this line as a starting point the phase angle of the current in the coil can be determined. If the coil and condenser are connected as in Figure 16 and the circuit is adjusted for maximum current in ammeters 1 and 2, the ammeters A_1 and A_2 give the current in the coil and condenser and the ammeter A gives the resultant current. If, as

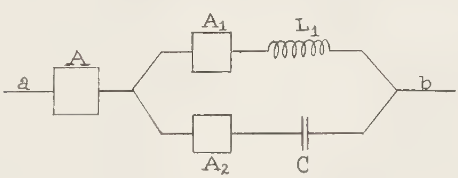


FIGURE 16.

in Figure 17 the E.M.F. is represented by the vertical line ab and the current I_2 through the condenser is drawn at right angles to the E.M.F., then the current I_1 and the current I, together with I_2, will form the parallelogram in which the line representing I is the vector sum. Vector difference would seem more appropriate. The angle, baI_1, the phase angle of the coil, depends upon the resistance of the coil. If the resistance of the coil is very small,

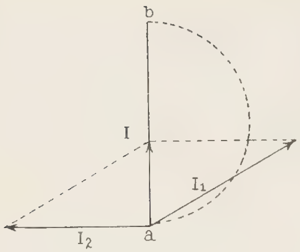


FIGURE 17.

then this angle becomes nearly ninety degrees, the two currents, I_1 and I_2 are nearly in opposite phase and then the reading of the ammeter A is the algebraic difference. If the condenser or coil is adjusted so that the ammeters A_1 and A_2 read the same, then the difference is nearly zero,—exactly zero if the two phase angles are each ninety degrees. Then our vector diagram is represented by the Figure 18. Thus if the resistance of both coil and condenser are zero, phase angles each ninety degrees, the resultant current is zero when the circuit is tuned to resonance.

Putting it in other words, if the resistance is zero, the impedance of the combination is infinite. However, the resistances are never exactly zero, so the limiting case is never reached, but the impedance can be made very large by selecting low resistance condensers and coils.

This is the fundamental theory of the wave trap. A coil and radio condenser are placed in parallel in the aerial of the receiving circuit and then tuned to resonance with the disturbing station.

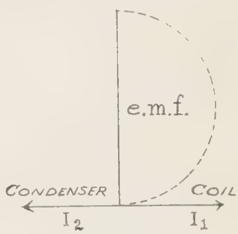


FIGURE 18.

71. Power in Alternating Circuits. The definition of work is force times space, but it is understood that the direction of the force and the space is the same. The formula for work might well be written $W = Fs \cos \theta$ where θ is the angle between the force and the direction of the space.

In alternating current, as a general thing, the current and E.M.F. are not exactly in phase and we have, power equals the E.M.F. times the current times the cosine of the phase angle, or $P = EI \cos \theta$. If the load is pure resistance, then $P = EI$, the cosine of zero being unity. In the equation $P = EI \cos \theta$ we can think of the cosine multiplying the current, or we have power equals E times the component of the current, which is in phase with the E.M.F. Also the equation can be written $P = IE \cos \theta$. In

this we can think of the power as being the current times the E.M.F. in phase with the current. This E.M.F. is IR as will be seen in the vector diagrams and the power becomes $P=I^2R$.

72. Transformers. A transformer is a device by means of which alternating current of low voltage is transformed to current of high voltage, or the reverse. When the transformation is from low to high voltage the transformer is called a step-up transformer. When transformation is from high to low voltage it is called a step-down transformer. A transformer may be used as a step-up or as a step-down transformer. Whether it is a step-up or a step-down transformer depends upon how it is being used.

Most transformers are used as voltage transformers. They are also used as current transformers. Most transformers have a closed magnetic path. The core of the transformer is in the form of a ring of iron. This ring is usually rectangular in shape instead of circular. A transformer may have an open core. Two coils wound on an iron rod or bundle of fine wire is an open core transformer.

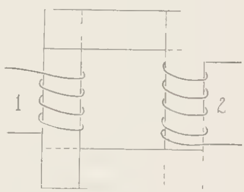


FIGURE 19.

The usual form of transformer is that in Figure 19. The core is laminated by being built up of strips of thin sheet iron into a rectangular core. The coils are first wound on a form and the core is built up inside the coils afterwards.

Two or more coils are placed on the legs of the transformer. Both coils may be placed on the same leg, or one coil on each leg. There is little difference. All the magnetic flux is supposed to take the path through the iron. If this is true, there is no difference.

The core is built of specially selected iron in which the hysteresis loss is small. The strips are rolled thin to prevent losses due to eddy currents. The thinner the iron the better.

Suppose a coil of 100 turns of wire, and suppose this coil is connected to a generator of 100 volts, 60 cycle alternating current. The current will increase in the coil until the "back" E.M.F. is equal to the impressed. The alternating magnetic flux through the iron core will be of such a value as to cause the "back" E.M.F. to be 100 volts. Suppose the second coil has 100 turns. The flux through the second is the same as that through the first coil, and

the E.M.F. in the second is 100 volts. The induced E.M.F. per turn of wire in both coils is one volt per turn. If the secondary coil has 10 turns or 1000 turns the secondary E.M.F. will be 10 volts or 1000 volts.

If the 100 volt secondary coil is connected to a resistance of 100 ohms, then the current in the secondary is one ampere.

Applying Lenz's Law, "The effect is in the direction to oppose the cause," the current will oppose the flux through the secondary coil. This flux is also the flux through the primary coil. Applying Lenz's Law to the primary, the flux is due to the current in the primary. Since the flux is opposed by a current of one ampere in the secondary, there must be more current in the primary coil to keep the flux constant. Then the current in the primary must be increased by one ampere.

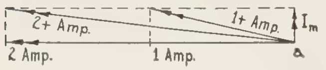


FIGURE 20.

The original small current in the primary was wattless current and at right angles to the E.M.F. The resultant current will be one ampere combined with a small current at an angle of ninety degrees. The vector diagram is a right angle triangle of large base, a small height, and a hypotenuse which is not much longer than the base.

The flux through the core is now the same as the original flux. If the secondary current is increased to 10 amperes the primary current increases to 10 amperes in phase with the secondary current and the flux has the same constant value, Figure 20.

If the primary voltage is increased to 150 volts the flux through the core is increased 50% and the secondary voltage is 150 volts. The primary voltage can not be increased indefinitely since the core becomes saturated, or goes above the "knee" of the magnetization curve. The flux does not all follow the iron path through the secondary coil and the hysteresis losses also become excessive. A transformer should not be used for voltages higher than that given by the manufacturer on the name plate.

If the secondary has 1000 turns and is connected to 10,000 ohms, the current will be 1/10 ampere. This flows 1000 times around the flux and it will require 1 ampere in the primary coil of 100 turns to keep the flux constant.

The primary power in this case is $EI \cos \theta$, θ supposed to be 0;

or $100 \times 1 = 100$ watts. The secondary is $1000 \times .1 = 100$ watts. The efficiency in this case is 100%. This on the assumption that the coils have no resistance and that the core has no hysteresis or eddy current loss. The usual efficiency in an actual transformer is near 95%.

In a theoretical transformer the product of EI on one side is equal to EI on the other. By stepping up the voltage, the line losses in long distance transmission can be greatly reduced.

73. The Magnetic Circuit. The magnetic circuit in the case of a transformer is the path through the core of the transformer. The length is the average length of the path for lines of force and the cross section is the cross section of the iron in the coil. In a magnetic circuit such as the magnetic circuit in a D.C. generator, the cross section is not constant and the path may be partly through cast iron and partly through wrought iron and through air.

The equation for flux, number of lines of force, is Flux equals magnetomotive force, M.M.F., divided by reluctance, Rel.

$$F = \frac{M.M.F.}{\text{Rel.}},$$

M.M.F. is that which causes the flux. M.M.F. $= 4\pi nI/10$, Rel. $= l/\mu\square$, where $\square$ or $\pi r^2 =$ cross section. See page 15 Chapter I.

$$F = \frac{4\pi nI}{(10l/\mu\pi r^2)} = \frac{\mu 4\pi^2 r^2 I}{10l}$$

If the path is not constant then,

$$\frac{\frac{4\pi nI}{10}}{\sum \frac{l}{\mu\square}} = \frac{4\pi nI}{10\left(\frac{l_1}{\mu\square_1} + \frac{l_2}{\mu\square_2} + \frac{l_3}{\mu\square_3} + \right)}$$

The lengths, cross sections and permeability of the various sections must be known.

Since $E = dF/dt = LdI/dt = LI\omega$ for alternating current,

$$E = \frac{dF}{dt} = d\left(\frac{\mu 4\pi n^2 \square I}{l}\right)\Big/dt = \mu 4\pi n_1{}^2\square\frac{dI}{dt} = L\frac{dI}{dt},$$

$$L = \frac{\mu 4\pi n_1^2 \square}{l}$$

L is proportional to n^2, the square of the total number of turns in the coil.

The E.M.F. in the secondary is $MI_1\omega = MdI_1/dt$.

$$E_2 = \frac{dF}{dt} = \frac{MdI_1}{dt} = d\left(\frac{\mu 4\pi \square n_1 n_2}{l}\right) / \, dt = \left(\frac{\mu 4\pi \square n_1 n_2}{l}\right)\frac{dI}{dt},$$

$M = \mu 4\pi \square n_1 n_2$: M is proportional to the product of $n_1 \times n_2$.

In radio work transformers are used for a source of high potential for spark transmitters. In continuous wave, C.W. or modulated continuous wave, C.W. transformers are used instead of A and B batteries. In C.W., such as radio telephone, the alternating current must be rectified and smoothed out, "ironed out" with condensers and choke coils.

CHAPTER V

INTRODUCTION TO RADIO

74. Resonant Circuits. Modern radio is based on resonant circuits, a particular phase of alternating currents. In the section on alternating current we saw that the equation for I, when there is inductance, resistance, and capacity in the circuit with an alternating E.M.F. is

$$I = \frac{E}{\sqrt{R^2 + (L\omega - 1/C\omega)^2}}$$

A particular case of this is when the term in the brackets, $(L\omega - 1/C\omega)$ is equal to zero, and then $I = E/R$.

If a rather large inductance and a condenser of from one to ten microfarads are connected in series with an ordinary glow lamp to a sixty-cycle circuit and the capacity or inductance varied, the lamp will glow brighter for certain adjustments. The brightness of the lamp indicates when the current is a maximum. To get a maximum the inductance required depends upon the particular value of the capacity in the condenser. In the vector diagram Figure 15 Chapter 4, it is shown that the E.M.F. due to the coil is just equal and opposite to the E.M.F. due to the condenser.

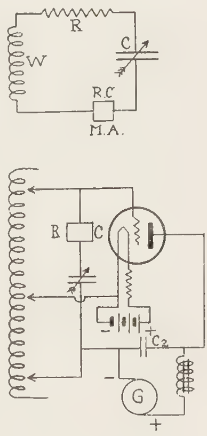


FIGURE 1.

If a high frequency oscillator or alternator is made of an amplifying tube or small power tube, it can be shown that a wave meter can be tuned to this circuit and make a small flash lamp glow.

The principle of the two experiments is the same. In the first case we have a sixty cycle circuit conveniently taken from the city mains, perhaps. In the other we have a million cycle circuit which is most conveniently obtained by a power tube connected to a Hartley circuit, Figure 1.

75. High Frequency Oscillator. This circuit, as can be seen from the diagram, Figure 1, consists of a coil and a good radio variable condenser connected to a radio frequency ammeter, R.C., in series. This will be seen to be what we shall call our wave meter circuit. One of the terminals of the coil is connected to the grid of a power tube, and a point near the middle of the coil is connected to the negative filament of the tube. The negative terminal of the B battery or generator is connected at the lower terminal of the coil, and the positive terminal is connected to the plate of the tube. A by-pass or blocking condenser is placed around the B battery or generator, and the D.C. meter in the plate circuit. This condenser should have a capacity of about .001 m.f. or more. The wave meter, consisting of a coil L, a variable radio condenser, C, and a small flash lamp or radio ammeter, is connected inductively to this oscillator.

The coils for both oscillator and wave meter may be exactly alike,—fifteen to thirty turns of heavy wire wound on a cylinder from four to six inches in diameter. For temporary work, oatmeal boxes will do. One of these should have a tap at the middle point. All connections should be made with short, heavy wires in order to reduce the resistance of the circuits. Care must be exercised in adjusting the wave meter circuit to resonance with the oscillator. The current increases through the lamp so rapidly that it may be burned out before one is aware of it. If a 210 tube is used the A battery must be $7\frac{1}{2}$ volts, and the B battery from 100 to 400 volts. By changing the capacity of the wave meter the wave meter can be tuned to the oscillator. By changing the condenser in the oscillator the frequency of the generator may be made the same as the natural or resonance frequency of the wave meter. If the inductances were variable we could tune by changing either the capacity, the inductance or the frequency in this experiment.

With the circuit from the mains the frequency is fixed and is not under our control, while with the high frequency circuit the frequency can be changed from 500,000 to 1,500,000, perhaps, simply by turning a knob on the generator condenser.

76. Tuning with C, L, or n. In the equation $1/C\omega = L\omega$ we have three factors—C, the capacity of the condenser, L, the inductance of the coil, and ω the angular velocity of our rotating vector (rotor or armature of a two pole generator).

$\omega = 2\pi n$ where n is the frequency. The current may be made a maximum by keeping two of these constant and changing the other.

With the high frequency circuit, the frequency can be changed. If the wave meter is set the generator can be tuned to the wave meter by changing the frequency. Since

$$L\omega = 1/C\omega,$$

$$\omega = 1/\sqrt{LC} \quad \text{where} \quad \omega = 2\pi n.$$

The frequency, $n = 1/(2\pi\sqrt{LC})$.

In Figure 1 the wave meter consists of a coil and a variable condenser and resistance connected in series. The resistance in this case is largely that of the small glow lamp. The glow lamp is not absolutely essential except as a means of telling when the current is a maximum. With the lamp left out we have the resistance of the coil and condenser in the circuit.

With a sixty cycle circuit we have the generator connected in series with the circuit. This is the source of the E.M.F. With the high frequency wave meter the E.M.F. is induced in the coil by induction from the coil in the oscillating circuit.

It is usual to apply the term oscillating to high frequency circuits, and alternating to low frequency circuits. There is no difference except in frequency. It is correct but unusual to speak of 100 million cycle alternating current, and of one cycle oscillating current. The frequency, n, of a circuit depends upon the product of L and C.

77. *Pendulum Analogy.* The frequency of a pendulum depends upon the length of the pendulum and upon the value of gravity. A pendulum tends to vibrate or "alternate" in its own natural frequency. If a small impulse is given to the pendulum at the proper times, a large vibration is built up. The frequency of this impulse must be the same as the natural frequency of the pendulum. With tuned circuits, the frequency of the E.M.F. must be the natural frequency of the circuit, in order to get any considerable current.

If the circuit oscillates it will, like the pendulum, naturally oscillate at its own natural frequency. This is what is happening in our tube oscillator. The circuit is such that the tube supplies

the energy of the B battery to the circuit at the right time or at the natural frequency of the circuit. This frequency is determined by the inductance and capacity,

$$n = 1/2\pi\sqrt{LC}.$$

78. The Condenser Annuls the Effect of the Inductance. If we look at our equation

$$I = \frac{E}{\sqrt{R^2 + (L\omega - 1/C\omega)^2}}$$

and consider that we make the current maximum by making the bracketed term zero, we see that we make the effect of the capacity annul the effect of the inductance.

This is what we are doing when we twist the knobs of a radio receiver. We are annuling the effect of the coil by means of the variable condenser. This annulment takes place at any particular time for one particular frequency. If this particular frequency happens to be the frequency of our favorite station, we get a maximum current and strong signals or music. The generator is the distant station which starts electro-magnetic waves that pass over, through, or by our aerial and cause an E.M.F. which causes a detectable current when the reactance of the coil is annuled by the reactance of the condenser.

The study of radio consists of the study of tuned or resonant circuits. Resonant circuits are made up of coils and condensers. Resistance is also found in these circuits. One of the objects in the study of radio resistance is to find how to get rid of as much of this resistance as possible.

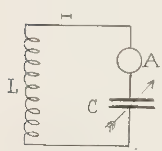


FIGURE 2.

79. The Wave Meter Circuit. The simple circuit as diagrammed in Figure 2 is the fundamental circuit used in radio. It consists of a variable condenser, a coil, and usually some indicating device connected together. This circuit is the same circuit used for series resonance in the section on alternating current. The coupling to the source may be by conduction, by capacity, or by induction. As a usual thing the coupling is inductive coupling. Thus Figure 1 shows a wave meter inductively coupled to an oscillator or tube generator.

In the fundamental equation,

$$I = \frac{E}{\sqrt{R^2 + (L\omega - 1/C\omega)^2}}$$

we have for resonance, $L\omega = 1/C\omega$ and $n = 1/2\pi\sqrt{LC}$.

Since in any wave motion $v = n\lambda$, where λ is the wave length, we can solve for λ. $\lambda = v/n = v2\pi\sqrt{LC}$ where v is the velocity of electromagnetic waves, which is 2.998×10^8 meters per second. (3×10^8 meters is the value usually used.)

80. Wave Length. If we have a tuning fork making 100 vibrations per second and we strike the fork and let it vibrate for one second, in this time the fork will have sent out 100 waves. The first wave has traveled a distance v during the second. At the end of the second there are 100 waves between the fork and the first wave disturbance. Then $\lambda = v/n$. If the v, velocity of sound, is 1100 feet per second, there are 100 waves each 11 feet long.

A single wave length is the distance the wave travels while the vibrating body, tuning fork in this case, is making one complete vibration. A wave is usually represented by the wavy line shown in Figure 3. A wave length is the distance from one crest to the next crest, a to e in Figure 3. It also is the distance from one trough to the next trough, c to g in the figure, or from b to f, points where the wave is in the same phase. A wave length is also the distance from h to i. It is usually assumed that the wavy line is a sine curve, or a curve in which the displacement in the vertical direction is proportional to the sine of the angle.

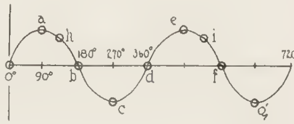


FIGURE 3.

Since we know the frequency, n, if we know L and C, we can calculate λ, the wave length of the disturbance set up in the ether by the oscillating current in the wave meter.

Here in the equation $\lambda = v2\pi\sqrt{LC}$, L is expressed in henries and C is expressed in farads. As a general thing it is more convenient or customary to express C in microfarads and L in microhenries. Then $\lambda = 2\pi \times 2.998 \times 10^8 \sqrt{L \times 10^{-6} \times C \times 10^{-6}}$ which when multiplied out is $\lambda = 1884\sqrt{LC}$ meters. L is expressed in microhenries, and C is expressed in microfarads. If the inductance is expressed in absolute e.m. units or centimeters and the capacity in microfarads, then $\lambda = 2\pi v\sqrt{L \times 10^{-9} \times C \times 10^{-6}}$.

$\lambda = 59.6\sqrt{LC}$ where L is expressed in centimeters and C is expressed in microfarads.

If a coil of known inductance and a calibrated variable condenser are at hand, the wave length can be calculated for several points and a curve drawn giving the wave length for every setting of the condenser. In using a wave meter an indicating device such as a small lamp is needed to indicate when the current is maximum. (For methods of measuring inductance and capacity see sections on inductance and capacity. For more detailed directions, see "Experimental Radio," Experiments No. 12 and 17.)

81. Wave Meter a Measuring Device. The wave meter is the fundamental measuring instrument used in radio. The wave meter occupies the same place in radio as that occupied by the galvanometer in electricity. Without a wave meter it is practically impossible to know much about the performance of radio apparatus. It is very important that the radio engineer or anyone who wishes to understand radio should have a full understanding of the wave meter theory.

Any coil when connected to a variable condenser and calibrated is a wave meter. The mystery of the wave meter is its simplicity! Wave meters can be calibrated in various ways, by calculation, as above, by comparison with a standard wave meter, by comparing with the Bureau of Standards, by using "constant frequency stations." (For Schedules see "Radio Service Bulletin," Supt. of Documents, Washington, D.C., 25 cents per year. See "Experimental Radio" for methods of calibration.)

82. Frequency Meters. The wave meter is a frequency meter and probably the name wave meter is a misnomer. Frequency, n, can be calculated and plotted as easily as wave length. The frequency can be obtained by dividing the velocity of light by the wave length—$n = v/\lambda$. Frequency should be plotted on the same sheet with the wave length. Figure 4 is a reproduction of a typical wave meter curve. The figure first gives the capacity of the condenser in the line marked "Capacity." This is seen to be a straight line except at the ends. Then λ^2, the square of the wave length, is given. This is seen to be a straight line except near the ends. From this line the value for the wave length, λ, is calculated by simply extracting the square root of the values read from the straight line, λ^2. The values of the wave length are shown on the

curve marked "λ." By dividing the values of the wave length into the velocity of light, the frequency in kilocycles is obtained and plotted in the curve marked "Frequency." These curves are for a 43-plate semicircular condenser and an 80 turn single layer coil wound on a paper tube $3\frac{1}{4}$ inches in diameter.

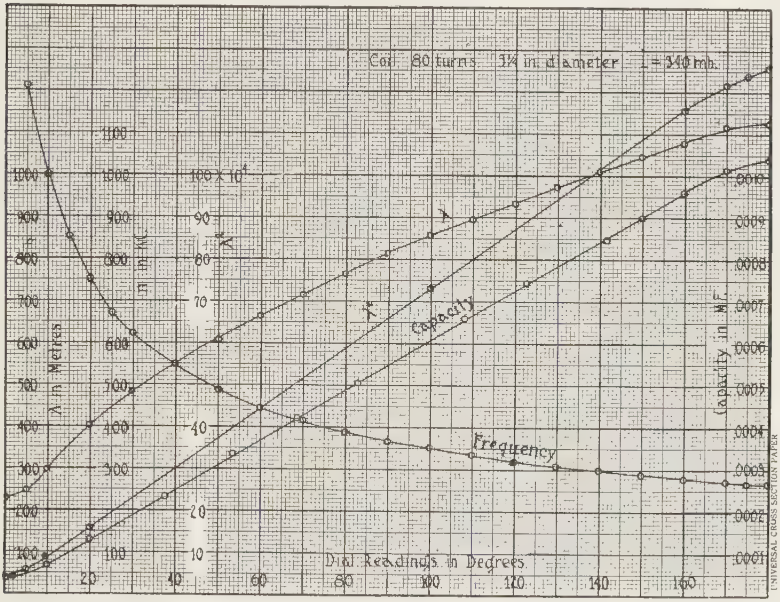


FIGURE 4.

83. The Wave Meter a Typical Circuit. The wave meter circuit as found in the typical wave meter is the fundamental circuit used in all radio circuits. Certain circuits may not seem at first sight to be like this one, but upon closer search they will be found to have capacity and inductance in the tuned circuit. There may be two or more condensers in series, which makes the circuit complicated, but remembering that two or more condensers in series are equivalent to a single condenser which is less than the smaller, we find the circuit simplified down to the simple circuit.

CHAPTER VI

CAPACITY

84. Introduction. When a charged body is brought near a second insulated body there is an induced charge on the second body. If the insulated body is touched a charge is taken off. If a ball Figure 1 is connected to a battery, the negative end of which is connected to the ground, and if this ball is moved towards a second body which is connected to the ground, there will be a negative charge induced on the second body, and if a sensitive instrument is placed in the battery circuit a small current will be found to be flowing towards the ball as it is moved towards the second body, and a second instrument will show that a current is flowing from the second body to the ground. The current will flow as long as the charged ball is moving toward the conductor. There is a certain quantity of electricity in the ball and this is increased as it is moved toward this conductor. Since Capacity = Quantity divided by Potential, $C = Q/V$, and since V, the E.M.F. of the battery is constant, the capacity of the ball is increased due to the fact that a second conductor is brought near to it. The capacity of any conductor is increased by the presence of other conductors. The two bodies constitute a condenser. Usually condensers are made of

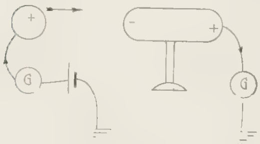


FIGURE 1.

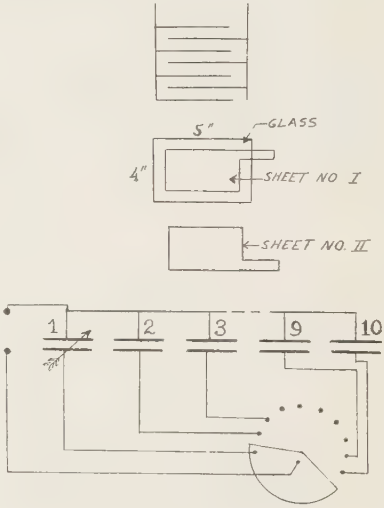


FIGURE 2.

conductors in the form of sheets of metal separated by air, glass, mica, or paraffined paper.

85. Fixed and Variable Condensers. In radio we have fixed and variable condensers. A fixed condenser may be made of two sheets of tin foil 3″ x 4″, pasted on a 4 x 5 inch photographic Plate. Figure 2 gives method of placing plates. Such a condenser has a capacity near .002 microfarads. A variable condenser consists of a number, usually about 43 or 21, or less, simicircular plates of metal, one-half of which are fixed and the other half mounted so as to rotate and pass between the fixed set but not touch. The maximum capacity is usually about .001 microfarads or .0005 microfarads.

86. Potential and Capacity. In the electro-static system of units the unit of capacity is the centimeter. It is the capacity of a sphere whose radius is one centimeter. The potential of a point at a distance R from a charge Q is Q/R. If a charge Q is placed on a point the potential of every point at a distance R from Q will be at the potential Q/R. This imaginary sphere is an equipotential surface. A conductor is also an equipotential surface. If a hollow conducting sphere of radius R, Figure 3, has a charge Q placed at the center of the sphere, the potential is Q/R also. Since moving Q about in the sphere does not have any effect on the potential of a conductor, and since the charge Q can be placed on the surface of the conductor and have the same effect on the potential of the conductor as if the charge Q is on the inside, then the potential of a sphere of radius R has the potential Q/R when the charge Q is on the sphere. Since $Q=CV$, quantity equals capacity times potential, then $V=Q/C=Q/R$, and $C=R$.

Sphere of radius R cm.
Capacity = R cm.

FIGURE 3.

87. Spherical Condenser. The capacity of a sphere is equal to the radius of the sphere. If another imaginary sphere of greater radius is drawn about the charged sphere, then this space has potential Q/R_2. If a second hollow sphere is placed so as to occupy this space, then the potential of the second sphere is Q/R_2.

The difference of potential of the two spheres is $V_1-V_2=Q(1/R_1-1/R_2)$.

If the outside sphere is connected to the ground, then $V_2=0$

and $V_1 = Q(1/R_1 - 1/R_2) = Q(R_2 - R_1)/(R_1R_2)$. Since $C = Q/V$, we have $R_1R_2/(R_1 - R_2)$ as the capacity of a spherical condenser.

If the spheres are large so that $R_1 = R_2$, nearly, and $R_1 - R_2 = d$, where d is the distance between the spheres, then $C = R^2/d$. Multiplying numerator and denominator by 4π we have $C = 4\pi R^2/4\pi d = S/4\pi d$, where S is the surface of the sphere. If the spheres are large, a small portion of the surface will be a plate condenser made of two plates and the capacity of the plate condenser is $C = S/4\pi d$.

If the plates are separated by a dielectric other than vacuum, then the capacity is increased by the dielectric, and $C = kS/4\pi d$, where k is the dielectric constant. Air is usually considered to have a dielectric constant of unity, the same as that of a vacuum. The exact dielectric constant of air is 1.00059. The dielectric constant of kerosene is 2, that of castor oil is about 4.5. The capacity of an ordinary air condenser immersed in castor oil is 4.5 times the capacity it has when filled with air. ("Experimental Radio," p. 92.)

88. Dielectric Constant. The dielectric constant of a substance can be defined as the ratio of the capacity of a condenser when the space between the plates is filled with the substance, to the capacity of the same condenser when the space is filled with air or vacuum.

The value of the dielectric constants of various substances is shown in the following Table of Dielectric Constants.

89. Capacity of a Condenser: Calculations. From the formula, $C = kS/4\pi d$, we see that we can increase the capacity of a condenser by increasing the surface, S, of the plates, or by using a substance of high dielectric constant, k, or by diminishing the distance, d, between the plates.

It will be evident that for high voltages the distance, d, cannot be diminished indefinitely. It is customary to increase the surface by using a pile of a number of plates instead of using two large plates. A sheet of metal, then a sheet of dielectric, glass perhaps, and then a sheet of metal until we have n plates of metal. The odd and the even sheets are connected for terminals. The surface is $n-1$ times the area of one sheet. Figure 2 shows the method of connection of the plates.

The capacity of a plate condenser can be calculated from the formula. If the plates are far apart there will be a correction for

TABLE OF DIELECTRIC CONSTANTS

Substances	Values of dielectric constant (k)	Substances	Values of dielectric constant (k)
Air	1.0	Celluloid	7 to 10
Glass	4 to 10	Wood, maple, dry	3.0 to 4.5
Mica	4 to 8	Wood, oak, dry	3.0 to 6.0
Hard Rubber	2 to 4	Molded insulating material, shellac base	4 to 7
Paraffin	2 to 3	Molded insulating material, phenolic base ("bakelite")	5.0 to 7.5
Paper, dry	1.5 to 3.0	Vulcanized Fibre	5 to 8
Paper (treated, as used in cables)	2.5 to 4.0	Castor Oil	4.7
Porcelain, unglazed	5 to 7	Transformer Oil	2.5
Sulphur	3.0 to 4.2	Water, distilled	81.0
Marble	9 to 12	Cottonseed Oil	3.1
Shellac	3.0 to 3.7		
Beeswax	3.2		
Silk	4.6		

(Bureau of Standards, Circular No. 40)

the edge effect. The edge effect will cause the capacity to be larger than the value obtained from the formula, $C = kS/4\pi d$. To reduce this value which is expressed in centimeters, to microfarads, divide by 900,000.

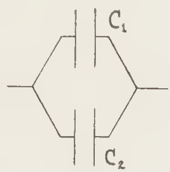


FIGURE 4.

90. Condensers in Parallel. If two condensers are placed in parallel, as in Figure 4, then $Q = q_1 + q_2$. Since $Q = CV$, and $q_1 = C_1V_1$, and $q_2 = C_2V_2$ and $V = V_1 = V_2$, then $CV = C_1V_1 + C_2V_2$ or $C = C_1 + C_2$. The capacity of two or more condensers in parallel is the sum of the separate values.

91. Condensers in Series. When condensers are in series, as in Figure 5, $Q = q_1 = q_2$ and $V = V_1 + V_2$, and since $V_1 = Q_1/C_1$ and $V_2 = V_2/C_2$, $Q/C = Q_1/C_1 + Q_2/C_2$ and $1/C = 1/C_1 + 1/C_2$. The capacity of two condensers in series is the reciprocal of the sum of the reciprocals of the capacities.

FIGURE 5.

It will be noted that the laws of combination of capacities are of the same form as the laws of combination of resistances except that capacities in series take the reciprocal law while resistances in parallel take the reciprocal law. Resistances in series take the summation law while capacities in parallel take the summation law.

It is well to remember that $Q=CV$ is analogous to a gas tank. The quantity of gas in a tank is equal to the volume of the tank times pressure.

92. Unit of Capacity, Microfarad. The capacity of a condenser may be defined as numerically equal to the quantity of electricity the condenser will hold when the potential at the terminals is one volt. The unit of capacity, in the practical system of units, is the farad. A condenser whose capacity is one farad will hold one coulomb of electricity if the potential of the terminals of the condenser is one volt. Note that the farad is a unit in the practical system. The centimeter is an absolute unit in the electro-static system. 900,000 centimeters make a microfarad. Instead of using condensers whose capacity is farads, we usually use one whose capacity is more nearly one millionth of a farad. This is called a microfarad. A microfarad is one-millionth, 10^{-6}, of a farad. Sometimes in radio the unit picrofarad is used. This is a millionth of a millionth of a farad, or a micro-micro-farad. The ordinary radio condenser may have 500 picrofarads capacity, or .0005 m.f.

A condenser whose capacity is one m.f. would have to consist of a very large number of sheets of metal separated by paper or mica.

93. Current through a Condenser. In alternating circuits the condenser is charged, discharged and charged in the opposite direction. This charging or flowing of the charge in and out is an alternating current.

We say that an alternating current will flow through a condenser and a direct current will not flow through the condenser. Although an alternating current ammeter may show a current flowing, there is no current, through the condenser in the sense of an individual electron flowing in at one terminal and out at the other terminal. When an electron flows in at one terminal, another electron is repelled and flows out of the other terminal. It is impossible for a particular electron to flow in at one terminal and out at the other terminal.

94. Practical Condensers. A condenser as we have seen is an assemblage of conductors and dielectrics (metallic plates and sheets of insulating material) arranged in such a manner as to give the effect of capacity. Although any assemblage of conductors and insulators will have a capacity, we usually want a capacity of a certain value, usually in a form which will occupy a small space.

95. Glass Plate Condensers. Glass plate condensers are used where a small capacity is wanted and where the potential is rather high. Their disadvantages are that they are rather bulky and that if they are subjected to an alternating E.M.F. the glass has considerable dielectric loss which causes the temperature to rise to a point where the effectiveness of the condenser is impaired. They have the advantage that they are cheap to make and if one has access to

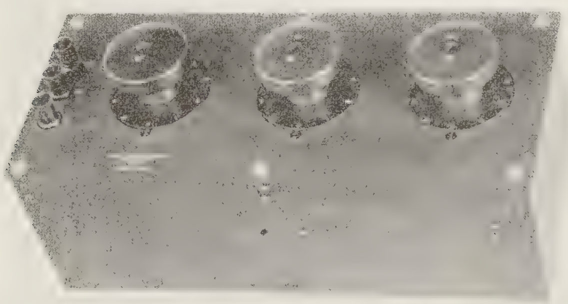


FIGURE 6. A variable standard condenser made by Leeds and Northrup Co. This condenser can be used as a standard with values from .001 M. F. to 1 M. F.

old photographic plates, their construction by a student gives him a first hand introduction to capacity which is not easily forgotten. The metallic plates are usually made of tinfoil, although the plates may be made of sheet metal of any material at hand.

96. Mica Condensers. The best fixed condensers are made with mica as the dielectric. Mica is the best dielectric used in condensers. It has a rather large dielectric constant. The dielectric strength is large, making a mica condenser able to withstand high potentials without puncturing or shortcircuiting. All good standard condensers are made with mica as a dielectric. Figure 6 is a picture of a standard mica condenser made by Leeds and Northrup. This condenser really is a number of condensers placed so that they may be placed in parallel by means of the sliding contacts.

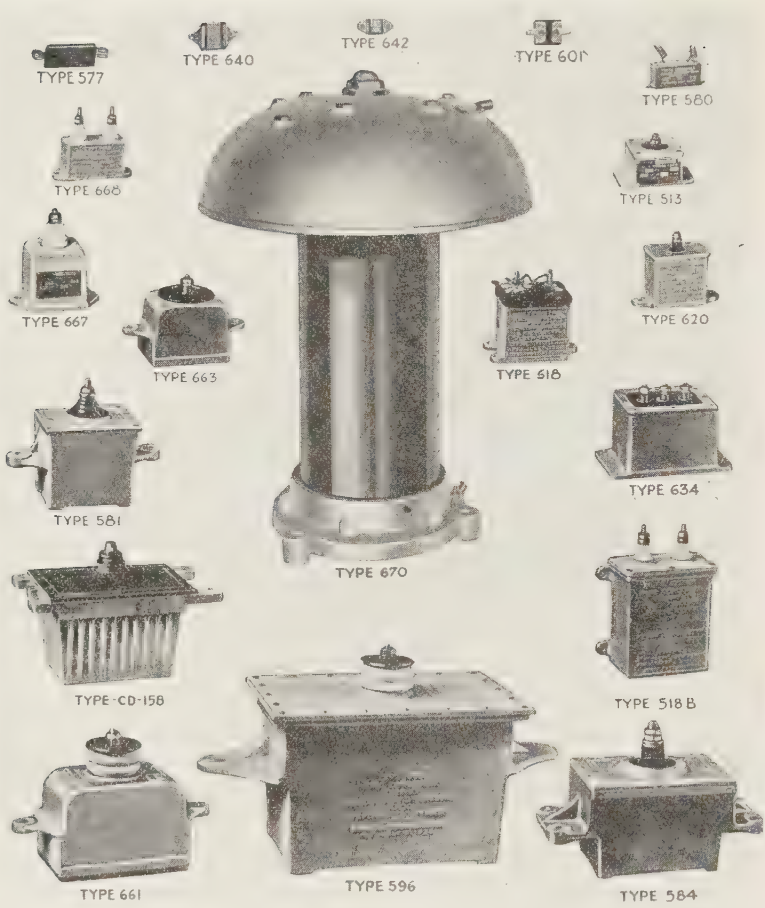


FIGURE 7. A number of condensers made by the Dubilier Condenser corporation. The mush room type in the middle is a coupling condenser used in carrier current, wired wireless, systems to permit telephoning over high potential transmission lines. All others condensers except the small one at the top are used in radio transmitters or generators. The large one at the bottom is used in generating circuits where the voltage is from 3000 to 12000 volts.

97. Fixed Radio Condensers. The small fixed radio condensers which are used in radio apparatus are usually mica condensers. Two or more small sheets of metal are separated with a thin sheet of mica and then are moulded inside bakelite or other material. Figure 7 shows a number of fixed radio condensers made by Dubilier Condenser Company. The mushroom condenser is a coupling condenser for carrier current transmission, Chapter 30, and is made to stand high potentials.

98. Filter Condensers. Filter condensers for B battery eliminators are usually made of paper or of paper impregnated with paraffine or other material for the dielectric. The metallic plate is usually made of tinfoil. The better grade of condensers, especially for high potential work, are made of mica. In choosing a filter condenser the proper capacity must be secured and the potential rating or guarantee should be scrutinized. The guarantee should be for A.C. potentials. A condenser of this type may stand a high D.C. potential all right, but heat and puncture when used under the fluctuating potential of the filter. The small radio condensers are often used as filter condensers to eliminate high frequency potentials.

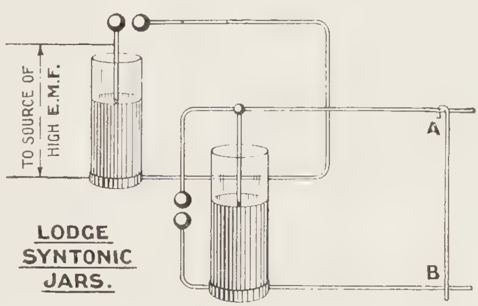


FIGURE 8. Leyden jars. These particular jars are connected to inductance of a single turn or rectangle of wire. One is a transmitter and the other is the receiver. The received current is "detected" when a tiny spark is seen. This experiment is one of the earliest experiments in electrical resonance.

99. High Potential Condensers. High potential condensers such as were formerly used for spark transmitters were often Leyden jars. These were simply glass jars which were coated inside and out with tinfoil. The better grades had copper coatings which were deposited on the glass by an electrolytic process. Figure 8 is that of a Leyden jar.

100. Oil Condensers. Oil condensers were often glass plate condensers which had one or more glass plates between the sheets of metal and the entire condenser immersed in a tank of oil. The oil increases the insulation of the condenser. An oil condenser may be an air condenser immersed in a jar of oil. Figure 8 Chapter 21 is an oil condenser used for spark transmission.

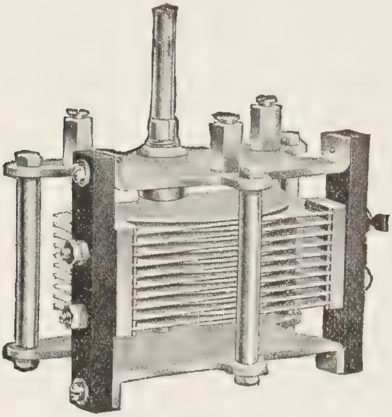


FIGURE 9. A low loss condenser. This condenser has semicircular plates. It is a straight line capacity condenser. Note sturdy structure. Condenser made by the Allen D. Cardwell Mfg. Co.

101. Impregnated Condensers. The condenser may be made and impregnated with an insulating compound with good dielectric strength and small dielectric or hysteresis loss. Many of the condensers in Figure 7 are impregnated condensers.

102. Variable Radio Condensers. The variable condenser consists of a number of semicircular or other shaped plates so arranged that alternate ones, rotor, rotate interleave and pass between but do not touch the fixed set, the stator. The exact construction of these variable condensers varies with the maker. The best types are known as the "low loss" type in which the rotor rotates in bearings which are in metallic contact with the frame of the condenser. The stators of these condensers are supported by hard rubber or other insulating material. In this manner the bearings can be made with precision and the insulating material can be placed at such points that the electric field is weak. The type where the rotor is supported by a bearing made of an insulating bushing or washers is usually rather wobbly and subjected to losses due to poor or dirty bushings.

103. Straight Line Capacity Condensers. The straight line capacity condenser is one in which the capacity is proportional to the dial reading. One which when the capacity is measured at various points on the dial, and when these readings are plotted against dial readings a straight line is obtained. The semicircular

plate condensers, the only kind made before about 1924, are straight line capacity condensers. Since the capacity is proportional to the surface of the plates, the area of semicircular sectors interleaved, is proportional to the dial reading. For experimental work these condensers have certain features which lend themselves to exact measurements. A straight line capacity condenser, if used as the variable condenser in a wave meter, will also give a straight line when the square of the wave length and dial readings are plotted. This is independent of the coil used and is quite an advantage in calibration work. Fig. 9 is a straight line capacity Cardwell condenser.

104. Straight Line Wave Length Condensers. A straight line wave length condenser is one in which the plates are so shaped that the capacity varies in the right manner to give a straight line if wave length and dial readings are plotted when the condenser is connected to a certain coil. If a second coil of different inductance and capacity is used, the line will not be straight. The condenser is a straight line wave length only when used with coils of certain construction.

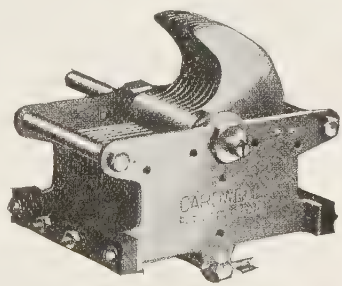


FIGURE 10. A shaped plate condenser. Low loss type. The plates may be shaped to give straight line wave length or straight line frequency when used with certain coils.

105. Straight Line Frequency Condensers. This condenser is, like the straight line wave length condenser, a shaped plate condenser. The plates are so shaped that the capacity is such that when the condenser is connected to a certain coil and frequency and dial readings are plotted, a straight line is obtained. This is of advantage in broadcast receiving, since the transmitting stations are scattered or allocated according to frequency. In the older receiving sets the short wave stations were very close together on the dial. With a straight line frequency condenser the stations are uniformly distributed on the dial. The shape of the curve depends upon the coil, and as a usual thing the line is not exactly straight. Figure 10 is a shaped plate condenser. Figure 11 shows modern variable condensers.

106. Vernier Condensers. The vernier condenser is mis-named. Someone at some time placed a slow motion device on a condenser so that the capacity could be changed very slowly. This person had had some experience with a spectrometer or surveying instruments and remembered that someone had said these instruments

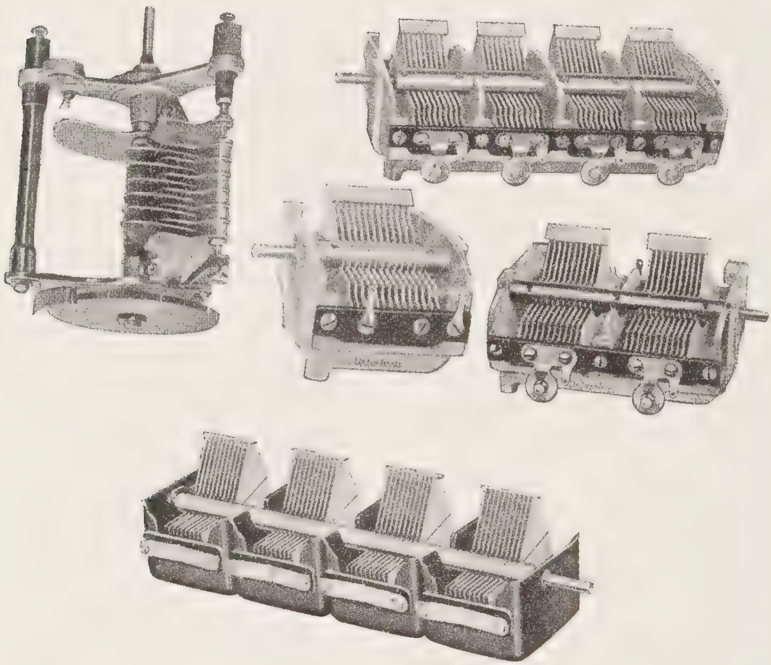


FIGURE 11.

had verniers on them. He also remembered the tangent screws or slow motion devices on these instruments and thought the slow motion device was the vernier. So a vernier condenser is one in which the capacity can be changed very slowly. A vernier is a scale so attached along side of the dial so that a small fraction of a division can be read accurately. Some dials have verniers attached so as to read a tenth of a division of the dial. A condenser fitted with a vernier scale is a true vernier condenser.

107. Comparison of Capacities. (See "Experimental Radio," Experiments No. 18, 19, 21, 22, 23.)

The capacity of condensers can be measured in several ways. The bridge method is probably the most simple.

The bridge consists of two known resistances and two condensers, one of which is known. Figure 12. The connection is made as in the figure. If we compare this to a resistance bridge we can say that instead of the battery we substitute a source of alternating current. Instead of the galvanometer we use a telephone head set.

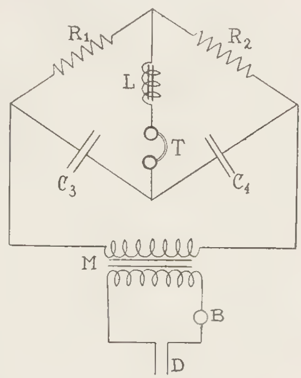


FIGURE 12.

In Figure 12 when the sound in the telephone is a minimum the current in the telephone is zero, the potential across the resistance, R_1 is the same as the potential across the condenser C_3 or $Pd_1 = Pd_3$. In like manner, $Pd_2 = Pd_4$ The current through the resistance, R_1 is the same as the current through the resistance, R_2. And the quantity of electricity in C_3 is the same as the quantity in C_4.

From the above we have, $I_1 = I_2$ and $Q_3 = Q_4$.

Since, $Pd_1 = I_1 R_1$ and $Pd_2 = I_2 R_2$ also $Pd_3 = Q_3/C_3$ and $Pd_4 = Q_4/C_4$ we have $I_1 R_1 = Q_3/C_3$ and $I_2 R_2 = Q_4/C_4$. Dividing the last two equations one by the other term by term, we have $R_1/R_2 = (1/C_3)/(1/C_4) = C_4/C_3$.

It is well to note that the bridge ratios are not made up in the same manner as when a resistance bridge is used. The ratio is made up by taking the arms of the bridge in order as we go around the bridge. If the bridge is used to measure resistances we do not take the arms in order but jump from bottom to top.

108. Resistance and Phase Angle of a Condenser. In a good air or mica condenser the resistance is very near zero and the current in the condenser is 90 degrees ahead of the electromotive force, Chapter 4. The phase angle of the condenser is 90 degrees and the phase difference is said to be zero.

In a poor condenser there may be an appreciable resistance in the connections, the condenser may leak, and there may be a dielectric loss in the condenser. The residual charge of a Leyden jar is due to this dielectric loss. If the jar is charged and discharged very

rapidly the glass will get hot, showing that there is a dissipation of energy which appears as heat.

Some of these heat losses may be in series with the condenser and others may be a high resistance path in parallel with the condenser. A resistance in parallel with a condenser can always be represented or the effect duplicated with a resistance in series with the condenser. See theory of alternating current.

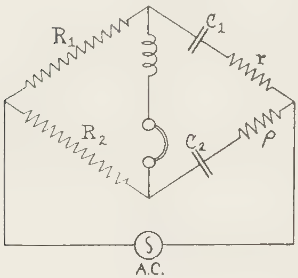


FIGURE 13.

If a good standard air condenser is compared with a paraffine paper condenser by the bridge method, the minimum sound in the condenser will not be good. The two currents in the two condensers are not a maximum at the same time. The phase angle of the good condenser is 90 degrees and the other is less than 90 degrees. If a resistance box is inserted in series with the good condenser in the bridge, Figure 13, the phase angle of that branch of the bridge can be made to equal that of the poor condenser.

When the best condition is obtained, then $R_1/R_2 = C_2/C_1 = r/\rho$, where ρ is the resistance in the condenser.

The phase angle of the condenser is $1/(\rho\ C\omega)$. Or the phase difference is the reciprocal or $\rho C\omega$ where ω is $2\pi n$, n being the frequency of the alternating source. For best results a good alternating source of pure wave form should be used instead of the buzzer.

The phase difference of a condenser is the difference between the phase angle of the condenser and 90 degrees.

CHAPTER VII

INDUCTANCE

109. Introduction. When a current flows in a wire or a coil it produces a magnetic field about the wire or in the coil. When a magnetic field changes about a wire or coil there is an induced E.M.F. in the wire or coil. The direction of the induced E.M.F. is such as to oppose the cause—the current, in this case. Thus we speak of an induced back E.M.F. in a coil through which the current is increasing. The E.M.F. is opposite to the current when the switch is closed, or on "make" and in the same direction as that of the current when the switch is opened, or on "break."

The induced E.M.F. in a coil when the current changes at the rate of one ampere per second is called the coefficient of induction, or the inductance of the coil. In absolute units the inductance is numerically equal to the number of lines of force threading through the coil when the current is one absolute unit of current, or ten amperes. The absolute unit of inductance is the centimeter. The practical unit of inductance is the henry. 1 henry $= 10^9$ centimeters. The millihenry is one thousandth of a henry. The microhenry is one millionth of a henry.

If one has a coil and allows the current to increase uniformly from zero amperes to one ampere in one second and measures the back E.M.F. induced in the coil while the current is increasing, then the inductance is numerically equal to the induced E.M.F. If the back E.M.F. is one volt, the inductance of the coil is one henry.

110. Inductance of a Solenoid. If in a long solenoidal coil, Figure 15, Chapter 1, whose length is so great that the end effects can be neglected, or if the ends are at infinity, or perhaps if the coil can be made into a large toroidal coil without ends, then the value of the magnetic field in the coil will be the same at all points on the inside of the coil when a current, I, flows through the coil.

The field, H, in the coil is $H = 4\pi nI = 4\pi NI/l$, where N is the total number of turns in the long coil and l is the length of the coil.

This is often written $H=4\pi NI/10l$. Where I, the current, is expressed in amperes.

To calculate the coefficient of inductance of this coil we will calculate the "back" E.M.F. in the coil when the current changes at the rate of one ampere per second. When the current is zero the field in the coil is zero. When the current is unity the field is $4\pi N/l$, absolute units. The number of lines in the coil is H times the area of the coil, or $H\pi r^2$. The total number of lines cut is equal to the total number of lines times the number of turns, N, or $(H\pi r^2)N$. The E.M.F. is equal to L, the inductance, since the current is supposed to change from zero to unity in one second.

$$L=\left(\frac{4\pi N}{l}\right)\pi r^2 N=\frac{4\pi^2 N^2 r^2}{l},$$

This is expressed in absolute units of inductance, or centimeters of inductance. One henry is equal to 10^9 centimeters. The value calculated by the above formula, must be divided by 10^9 to reduce to henrys. This formula can be written $4\pi^2r^2n^2l$. Where n is the number of turns per centimeter.

This formula is for an endless coil or for a coil so long that the ends do not have an effect. The coil must be long compared to the radius—a long slim coil—in order for the formula to hold. For an ordinary coil the value will be reduced by "end corrections."

$L=4\pi^2r^2n^2lK$, where K is a constant varying as $2r/l$. For table of correction for ends see "Experimental Radio," p. 34.

After the end corrections are made, if exactness is desired correction must be made for the fact that the current is not a "current sheet."

The calculation of the exact inductance of a coil requires a complicated formula and considerable time to make the involved computation. As a general thing it is better to measure the inductance by some experimental method.

111. Coils in Series. If two inductances are connected in series, then the self inductance of the combination is L_1+L_2 if there is no mutual effect between coils. See Chapter IV on Alternating Current, Section 63, for inductances in series and Section 64 for inductances in multiple.

112. Mutual Inductance. If a second coil is in the field of the

first coil there will be an E.M.F. induced in coil No. 2 by the current in coil No. 1, due to mutual inductance.

Mutual inductance, M, may be defined as follows: The coefficient of mutual inductance, M, is numerically equal to the electromotive force induced in coil No. 2 when the current in coil No. 1 is changing at the rate of one ampere per second. The unit of mutual inductance is the henry, the same as that for self-inductance.

If the two coils are so situated that all the lines of force from coil No. 1 go through coil No. 2, then

$$M = 4\pi^2 n_1 r^2 n_2.$$

If two coils are connected together and so situated that there is a mutual inductance, M, between them, then

$$L = L_1 + L_2 \pm 2M$$

the positive sign being used when the fields of the two coils are in the same direction and the negative sign being used when the fields oppose each other.

From the above it will be seen that M_{12}, the mutual inductance in coil No. 2 due to current in coil No. 1 is equal to M_{21}, the mutual inductance in Coil No. 1 due to current in coil No. 2 $M_{12} = M_{21}$.

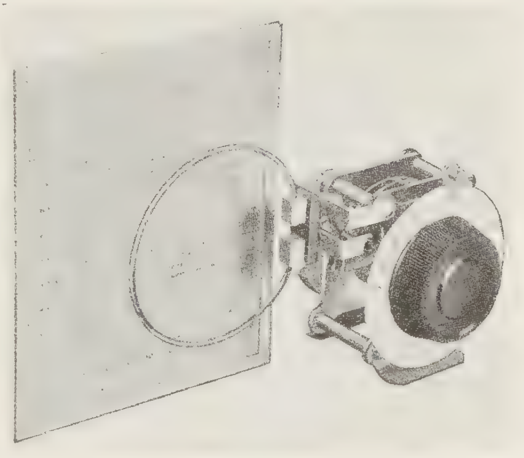


FIGURE 1.

113. Inductance Coils. Every coil, in fact, a single straight wire has inductance. Radio coils may be in various forms depending on the purpose for which they are intended. For short wave work the coil may be a single turn of wire bent

into a circle an inch or two in diameter. Figure 1 shows a wave meter for 5 meters. A turn of wire and a variable condenser.

114. Single Layer Coils. Except for very long wave lengths the form usually used is the single layer solenoid, Figure 2, A and C. Measurements show that when the single layer coil is wound on a

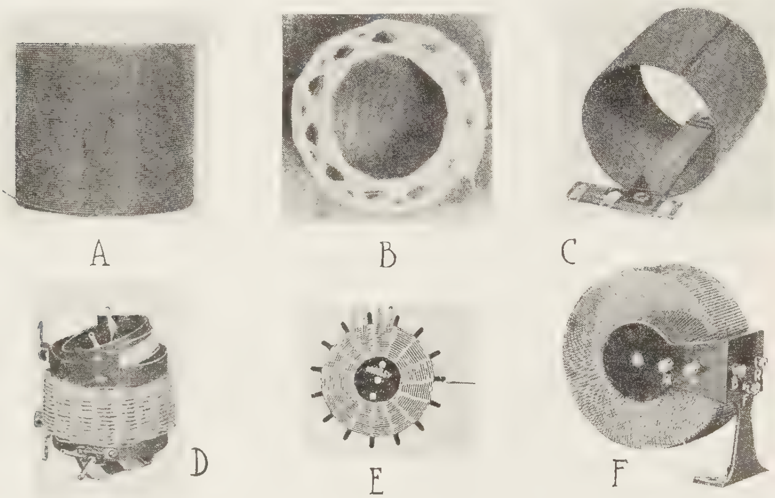


FIGURE 2.

good hard rubber tube it is, as a general thing, the most efficient form. If the tube is made of material of high dielectric loss, the resistance of the coil is increased and thus the efficiency is reduced.

115. Basket Weave Coils. In order to reduce the loss due to the form or tube on which the wire is wound, a self-supporting coil has been made by winding the coil on a form consisting of an uneven number of pegs or nails set in a board, equally spaced in a circle. Figure 2 B and D illustrates coils made on these forms. The wire is wound in and out alternately, making a basket weave. It is then tied with cord or cemented with celluloid. Another form of basket weave coil is one in which an uneven number of spokes or pins are placed around the circumference of a wooden or metal disc. The wire is wound in and out, tied or cemented, and the spokes removed. In some a light radial form is used and retained permanently, Figure 2E. These make neat looking coils if they are wound carefully and are rather efficient.

116. Bank Wound Coils. Where large inductance is wanted for long wave work the coil may be wound with two or more layers, Figure 3. This increases the capacity of the coil. If a coil having twelve turns per layer, say, is wound, and a second layer is placed on top of this layer, the twenty-fourth turn is on top of the first turn and the potential between these two turns is large, making the capacity effect large. The capacity of the coil is the summation of all these effects between all the turns. To avoid some of the increased capacity the coils are often bank wound as in Figure 3. Here the potential between any two turns of wire is not large.

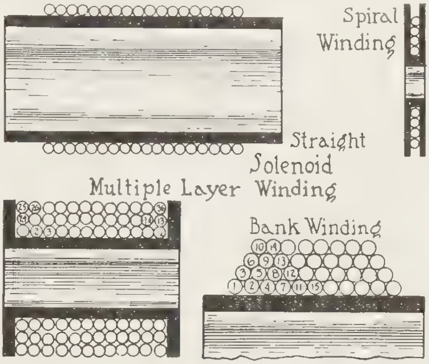


FIGURE 3.

117. Honey-Comb Coils. Honey-comb coils are coils which are wound in a peculiar manner, zigzag across the coil leaving open spaces in order to reduce the self-capacity of the coils. They are very convenient and make good receiving coils. They are often used in filter circuits where certain bands of frequencies are filtered out.

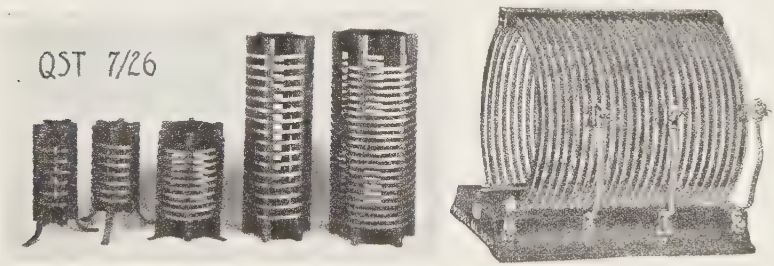


FIGURE 4.

118. Transmitting Coils. Transmitting coils carry a relatively large current and are usually made of heavy copper wire, rods or tubes. As a usual thing the copper is wound on a skeleton form so as to make a cylindrical coil. The form is made of bakelite. Dry wood impregnated with oil makes excellent forms. The spacing between turns is comparable to the diameter of the copper. Instead of copper wire sometimes copper bars or ribbon is used. The bar is wound in a thin, flat coil and held by supports forming a flat coil, sometimes called a pancake coil. Sometimes the bar or ribbon is rolled so as to form a spiral, and the coil is in the form of a cylinder called an edgewise ribbon coil.

Figure 4 shows edgewise and spiral ribbon coils.

119. Toroidal Coils. A toroid coil is a long solenoidal coil bent around so the two ends come together, Figure 2F. The coil has no end and since the field of a coil is supposed to come out of the ends of the coil, there is therefore no field outside this coil. The field is uniform and remains inside the coil. If two such coils are placed near each other there will be no mutual induction, since there is no field outside the coil. For this to be exactly true the current should be a sheet of current flowing around the space which the wire is supposed to occupy. Since the current flows in the wire and there is space between the wire, this is not exactly true and there will be some mutual induction or "pick up" between two toroidal coils.

120. Figure Eight Coils. Figure eight coils or binocular coils are coils which are supposed to limit the field after the same general manner of toroidal coils.

121. Low Loss Coils. Low loss coils are made in various forms which are supposed to have low resistance. Basket weave coils and coils wound on skeleton frames are some of the forms which have figured as low loss coils.

122. Iron Core Coils. Where coils of great inductances are needed, one henry or more, iron core coils are used. All audio transformers and choke coils are of this type. Since the inductance is proportional to the number of lines of force, the inductance is greatly increased when iron is placed in the coil. The inductance is increased to an amount represented by the permeability of the iron. Since the permeability of iron depends on the field which in turn depends on the current in the coil, the inductance of iron core coils is not constant. Iron always introduces hysteresis and eddy

current losses. The hysteresis loss can be reduced by selecting iron of small hysteresis. The eddy current loss is reduced by laminating the iron in the core. Figure 5 shows coils and core. The iron in transformers is laminated by rolling it into thin sheets and then cutting the sheets into strips so the core can be built up. The thinner the sheet the better the lamination. Cheap audio transformers have cores which are built up from iron sheets which are relatively thick.

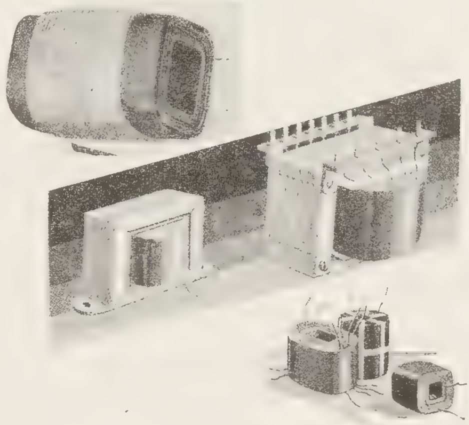


FIGURE 5.

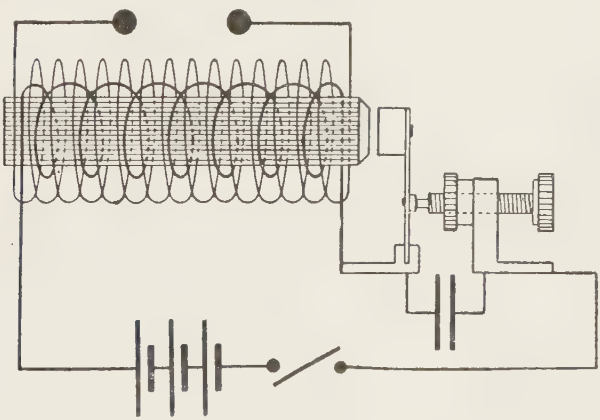


FIGURE 6.

123. Iron Dust Core Coils. In long wave work coils are sometimes built with iron cores. In order to reduce the eddy current loss the iron is ground into fine particles or dust and then this dust

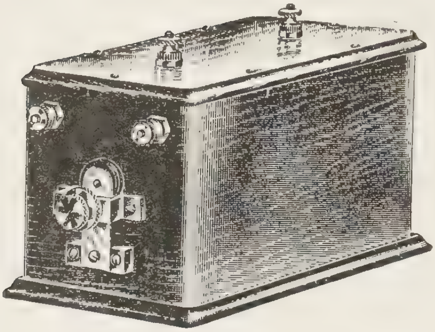


FIGURE 7.

is mixed with a binder such as shellac, formed and then baked. It was said some years ago that iron core coils would not work in radio circuits because the molecules or elementary magnets could not turn over fast enough. It is now known that the trouble was in the lamination. The eddy current in the core was practically equal and opposite to the current in the coil and the iron was shielded from the field of the high frequency current.

Figure 6 shows a diagram of the Ruhmkorff induction coil which was used in the early transmitting stations. Figure 7 shows a Ford coil which is a form of Ruhmkorff coil and was formerly used by amateurs in operating small power spark transmitters.

CHAPTER VIII

RADIO WAVES; RADIO CURRENT; TRANSMISSION

124. General Statement. In Chapter 4, Alternating Current, we have said that radio current was alternating current of high frequency. We have shown a tube oscillator, Figure 1, Chapter 5, which generates high frequency or radio current. In this the current can be represented by a sinusoidal curve of constant amplitude, or a sine curve in which the maximum height of all the waves is the same.

Radio frequency current can be excited in an aerial either antenna or coil. This current creates certain disturbances in the ether near the antenna. These disturbances are transmitted to distant points through the ether in the form which we call electromagnetic waves. These waves as they pass by a receiving aerial cause an E.M.F. in the aerial. This E.M.F. causes a current to flow in the aerial and in the receiving apparatus, provided that the circuits are tuned to the same frequency as that of the transmitting apparatus. These receiving circuits will be seen to be our wave meter circuits.

FIGURE 1. A modern screen grid tube for alternating current.

The current, the E.M.F., and the wave may be represented by the same wavy line, or they may be represented by different curves of different amplitude. But the frequency of all the curves must be the same. If for any reason the current should differ from a pure sine curve, the E.M.F. and the electromagnetic wave will differ in the same manner. At times we may speak of a wave when we mean the current which caused the wave in space, or perhaps we mean the current in the receiver produced by the wave.

125. Continuous Wave Transmitter. The apparatus in Figure 1, Chapter 5, gives current of constant value or amplitude and might be called a C.W. transmitter, C.W. standing for the words continuous waves. If a key is placed in the

circuit so as to open and close the circuit we have I.C.W., interrupted continuous waves. If by some device the amplitude of the current or-value of the current is made to change rapidly, we have modulated continuous waves or M.C.W.

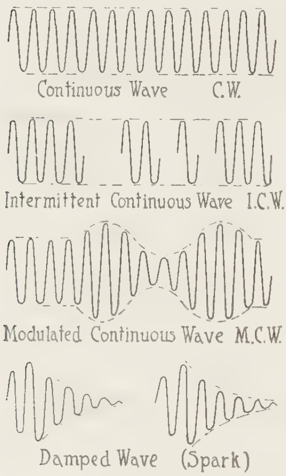


FIGURE 2.

Figure 2 gives diagrams illustrating C.W., I.C.W., M.C.W., and also damped waves. Damped waves can be seen to be a mixture of I.C.W. and M.C.W.

126. Damped Waves. Historically, damped waves or current were the first used for transmitting radio messages. The generation of current of this type or form depends upon the oscillatory discharge of a Leyden jar. The jar is charged up and then is discharged through an Inductance. If the resistance is not too large the discharge is oscillatory. If a pendulum is given a big push and left alone it will vibrate and gradually die down. If a pen or pencil were fastened to the pendulum and a piece of paper were moved at right angles to the vibration, a line would be drawn which would be the same form as that which represents a damped wave.

127. Generation of Damped Waves. The subject of damped waves will be taken up later in more detail. Suffice it to say that the equation of the current which produces a damped wave is $I = I_0 e^{-\alpha t} \sin \omega t$. The curve is a sine curve in which the amplitude diminishes logarithmically with time. The "spark" stations which were used on ships and by amateurs before 1920–23 were damped wave stations. Figure 3 is a diagram of a spark sending station.

128. Buzzer Excitation. In experimental work it is convenient in using a buzzer connected to a wave meter in order to generate high frequency oscillations. These oscillations are exactly the same as those produced by a spark station. The connections are shown in Figure 4. L and C represent the wave meter. A buzzer in series with a dry cell is connected to the terminals of the coil. A buzzer works on the same principle as a door bell and opens and

closes the circuit several times per second. When the current is flowing through the coil the potential of the point, a, is higher than that of the other terminal. The condenser C is then charged to a potential whose value is a fraction of a volt. When the buzzer opens the circuit the condenser discharges through the coil

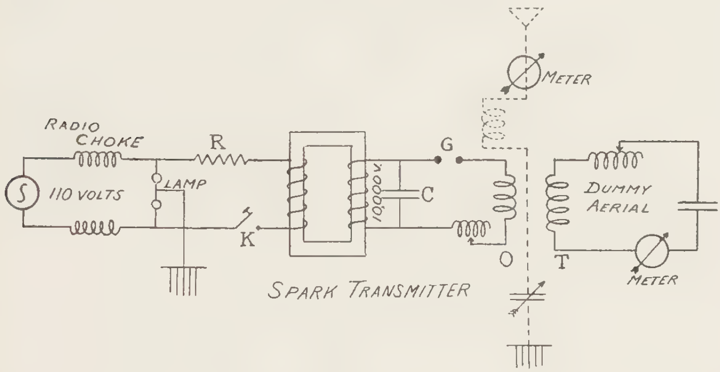


FIGURE 3.

and the discharge is oscillatory. The frequency of the oscillation depends on the value of L and C. The exact value of n is $n=(1/2\pi)\sqrt{(1/CL)-(R^2/4L)}$. (See Chapter 21.) When the resistance, R, is small enough to be neglected, the frequency becomes

$$n=\frac{1}{2\pi\sqrt{LC}}$$

This is the same formula for frequencies as that of a C.W. circuit when tuned to resonance.

If we have resistance, inductance and capacity in an alternating circuit the equation for the current is

$$I=\frac{E}{\sqrt{R^2+\left(L\omega-\frac{1}{C\omega}\right)^2}}.$$

If the inductance is zero, then

$$I=\frac{E}{\sqrt{R^2+(1/C\omega)^2}}.$$

The reactance is $1/C\omega$ instead of $L\omega$, as it is when a coil is in the circuit. The condenser causes a phase angle but this is positive instead of negative, as the angle is when inductance is in the circuit.

When the resistance as well as the inductance is zero, the equation for the current is $I=CE\omega$ and the phase angle is 90° positive.

If the resistance is zero and the capacity is infinite so that we have inductance alone in the circuit, the equation is $I=E/L\omega$ and the phase angle is 90° negative.

The vector diagrams for resistance and capacity are exactly like those for inductance and resistance except the reactance is now $I/C\omega$ and the phase angles must be considered to be positive. The graphical solutions are exactly the same. See Chapter 4.

In radio we always have resistance, inductance and capacity and the current,

$$I=\frac{E}{\sqrt{R^2+(L\omega-1/C\omega)^2}}\cdot$$

The reactance is $(L\omega-1/C\omega)$. The phase angle is positive or negative depending upon whether the capacity or the inductance plays the predominant part.

If $L\omega=1/C\omega$ then the reactance is zero and the current is a maximum, or $I=E/R$ and the phase angle is zero.

If $L\omega=1/C\omega$ then, $\omega=1/\sqrt{CL}$. Since $\omega=2\pi n$, $n=1/(2\pi\sqrt{LC})$.

In any vibrating body the natural frequency is that in which a small cause will produce the greatest effect. (A small tapping with a lead pencil will finally produce an appreciable amplitude in a heavy pendulum.) The natural frequency of a circuit is that given by $n=1/(2\pi\sqrt{LC})$, because the current at that frequency is the greatest.

129. n is not the Frequency of the Spark. It must be remembered that the frequency, n, in damped waves, refers to the frequency of the oscillatory circuit and not to the frequency of the buzzer. The buzzer frequency or spark frequency determines the number of groups of waves or the number of bunches of oscillations per second. Each time the buzzer opens the circuit the current oscillates through the coil a number of times with a fre-

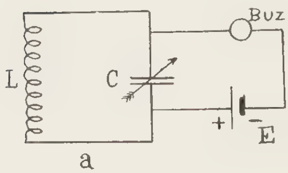


FIGURE 4.

quency, n, and dies down to zero. Then there is a relatively long time when there is no current. This is illustrated in Figure 4, Chapter 21.

If the current oscillates one hundred times before it becomes zero and the buzzer opens the circuit 100 times, then there is current in the coil one per cent of the time if the frequency, n, is one million vibrations per second,—300 meters.

When discussing the theory of vacuum tubes it is convenient to represent the radio current, waves, or E.M.F. by a damped sine curve. This can be considered to be a particular kind of modulated C.W. wave. In actual practice at the present we deal with modulated waves much more than with damped waves.

CHAPTER IX

DETECTORS

130. Why Need a Detector? In radio telegraphy and radio telephony alternating current is used. The telephone is the most simple and sensitive instrument for the detection and measurement of small alternating currents. The telephone depends upon the human ear to estimate the current strength. The frequency range of the telephone as used is limited by the frequency of the human ear. The upper range of the human ear varies with different persons but may be placed at less than 30,000 cycles per second. Most telephones with heavy diaphragms do not respond very loudly at the higher audible ranges. With a frequency of perhaps 20,000 cycles to 50,000,000 cycles per second the telephone by itself will not respond audibly.

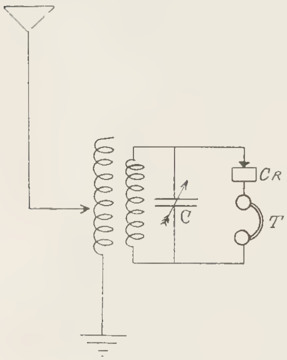


FIGURE 1.

If an alternating current of one million cycles passed through a telephone one of two things happen—either the diaphragm will vibrate or it will not vibrate. In either case the ear will not respond. Assume we are listening to a damped wave, spark station, Figure 1. The signals or currents in the receiving aerial can be represented as in Figure 2. The current through the receiving apparatus is damped alternating current which is made up of groups of perhaps one hundred oscillations at a frequency of one million cycles per second. After a relatively long interval, one ten thousandth part of a second, there is another group, there being perhaps one hundred of these groups in a second. Figure 4,

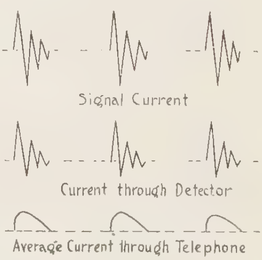


FIGURE 2.

Chapter 21 gives an idea of the relative time. If this current frequency was ordinary 60 cycle per second and passed through an ordinary D.C. ammeter the needle would in all probability remain fixed at zero. If the moving system were light enough it would vibrate about zero. On the average the current which flows in the positive direction is just equal to the current which flows in the negative direction. If a rectifier is placed in series with the ammeter, then there will be more current flowing in one direction than in the other, and the ammeter will give a deflection showing a direct current. This is because the rectifier conducts better in one direction than in the other, and the current in the negative direction is much smaller than the current in the positive direction. All storage battery charging devices which charge the battery from alternating current have some such device which acts as a rectifier.

The rectifier in series with the telephone in radio circuits is called a detector. There are many detectors which have been used. The two in common use today are the crystal detector and the tube detector.

131. Crystal Detector. Many crystals have the property of conducting better in one direction than in the other. The crystals in common use are galena, carborundum, silicon and zincite. Figure 3 shows a crystal detector with a "cat whisker." It is said that a piece of common coal will act as a detector to some extent. Crystal detectors were used in all receiving sets before the introduction of the vacuum tube—from about 1906 to 1920.

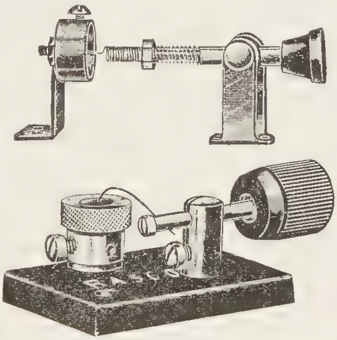


FIGURE 3.

Crystal detectors are used at the present time as "crystal receivers" for receiving from local broadcasting stations and in wave meters. Their simplicity and cheapness, as well as their fair efficiency, commend them.

132. Curved Characteristic. All detectors have a curved characteristic. If we measure the resistance of a crystal and then reverse the current and measure again we get another value. As a general

thing the resistance depends upon the value of the current as well as the direction of the current. Since resistance is the ratio of E to I, if we plot the potential across the crystal as abscissas and the current as ordinates we will get a straight line if the resistance is constant and a curved line if the resistance changes with current.

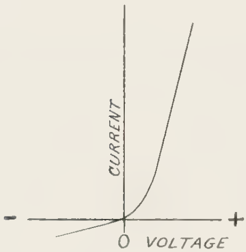


FIGURE 4.

Figure 4 is such a curve, assuming the resistance changes with direction of current. Figure 5 is the usual form of the curve showing that the resistance changes with the value of the current. Figure 5 gives the characteristic curves for a carborundum detector. In the carborundum crystal the point of greatest curvature is at a potential of about .8 volts. If a battery or potentiometer is placed so as to place a positive potential of .8 volts on the crystal all the time, the efficiency of this detector will be increased.

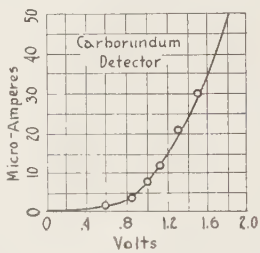


FIGURE 5.

133. Simple Crystal Receiver. Figure 1 is a diagram of a simple, two coil crystal receiver. The primary or aerial circuit is tuned to the transmitting station by means of the sliding contact on the coil in the aerial circuit and the secondary circuit is tuned to the same frequency by the condenser, C. The Pd across the condenser is the greatest when the current is greatest. The Pd across the condenser is also that across the phone and crystal which are in series. When the Pd is positive more current flows through the phone circuit than when the Pd is negative.

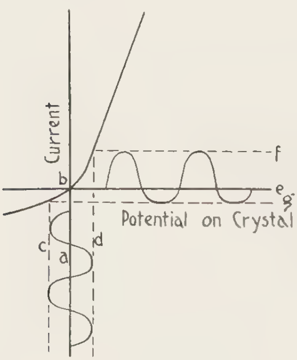


FIGURE 6.

The wavy lines which die out represent what are called damped waves. If Figure 6 represents the charac-

teristic curve of the crystal and if the potential across the crystal fluctuates as is represented by the damped wave about the line *ab*, when the potential is positive the current is represented by the line *f*. When the potential is negative the negative current is represented by the line *g*. It will be seen that the positive current is greater than the negative value and there is an increase of current through the phone in the positive direction. Figure 2 in connection with Figure 6 will explain.

The first group or bunches of wavy lines in Figure 2 represents the current in the aerial, also the *Pd* across the condenser. The second line of waves represents the current through the crystal. The current in the upper half or positive half is greater than in the negative half. The curve is a damped sine curve with the lower half cut off. The third line represents the average current through the phone. The average current in the phone when no signal is being received is zero. The "average" current pulsates, or comes in pulses of current,—one pulse for each group of waves which pass over or by the aerial. The actual current through the telephone will be the same form as the current through the crystal unless it is "smoothed out" or "ironed out" in the same manner as the current in B battery eliminators is filtered out. This is done by placing inductance in series and capacity in parallel.

A condenser is often placed across the telephone or across the crystal. More often these are omitted. The telephone is a coil of wire wound on an iron core, thus it is an inductance. The telephone cords are two wires which are close together and have capacity. This capacity and inductance is large enough to smooth the current out. Each bunch of waves passing over the aerial causes a pulse of current through the phone and the ear hears a click. If there are 100 bunches per second, the ear will hear 100 clicks per second, which will give a musical tone of frequency of 100.

134. Action of the Telephone. Another way of explaining the action of the telephone and detector is to assume that the telephone will vibrate at radio frequency. The telephone consists of a permanent magnet with a coil of wire wound around the pole. Current through the coil either strengthens the magnet or weakens it according to the direction of the current. Figure 7 is a diagram of a simple phone which has a bar magnet. The diaphragm is drawn

down toward the pole and made concave (much magnified in the diagram). When there is no current in the phone the diaphragm is in the position at A. If radio frequency current passes through the phone the vibration is about the mean position A. Since the mean position is the same as when there is no current, there is no audible sound. If the current is rectified, or detected, more radio frequency current passes through the phone in the positive direction than in the negative direction and the average value of the strength of pole is increased and the diaphragm oscillates about the average position shown at B. The change of the average position from A to B gives an audible click.

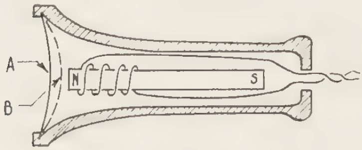


FIGURE 7.

135. General Theory of Rectification. Let $I=f(V)$ where I is the normal or steady current and V is the potential on the rectifier. Then, $I+i=f(V+e)$ where i is the rectified current and e is the potential of the signal, where $e=e_0 \sin \omega t$. By Taylor's expansion, if $I=f(V)$,

$$I+i=f(V)+ef'(V)+[e^2/2]\,[f''(V)]+[e^3/3]\,[f'''(V)]+\cdots$$

where $f'(V)$, etc, are the derivatives of $f(V)$ with respect to V.

Then since

$$I=f(V),\ \frac{dI}{dV}=f'(V),\ \frac{d^2I}{dV^2}=f''(V) \text{ and } \frac{d^3I}{dV^3}=f'''(V).$$

Then

$$i=e\frac{dI}{dV}+\frac{e^2}{2}\,\frac{d^2I}{dV^2}+\frac{e^3}{3}\,\frac{d^3I}{dV^3}+\cdots.$$

The average value of i is the average value $ef'(V)+[e/2]\,[f''(V)]+\cdots$.

Since $e=e_0 \sin \omega t$, the average value of e is zero, and the average of e^2 is $e_0^2/2$, or the root mean square of a sine function. The average of $e^3=0$.

The rectified current is the mean value of i and mean $i=(e_0^2/2)\ (1/2)(d^2I/dV^2)=(e_0^2/4)(d^2I/dV^2)$, powers higher than the third being neglected.

e_0 is the maximum value of the signal potential and is proportional to the virtual value of the potential of the signal, since the signal is an oscillatory potential.

Referring to the characteristic of the detector, I is the point on the curve at 0, Figure 4, dI/dV is the slope of the curve at 0, d^2I/dV^2 is the rate of change of the slope, or d^2I/dV^2 is the curvature of the curve at 0.

This shows that the signal current is proportional to the square of the potential and is also proportional to the curvature of the characteristic curve.

If the characteristic curve is a straight line, dI/dV is constant, the rectified current is zero and no signal is received.

To get loud signals the high frequency current should be amplified and the detector characteristic should have a large curvature and the detector potential should be adjusted so as to operate at the point of greatest curvature. An amplification of ten at radio frequency is equivalent to an amplification of a hundred at audio frequency, since the detected current is proportional to e^2.

136. Detector Receiving M.C.W. When the radio frequency current is modulated continuous current or or M.C.W. such as that in a radio telephone, the action of the detector is illustrated in Figure 8. The action is identical with that when damped waves are received. We have the incoming signal which is impressed on the detector, then the current through the crystal which has the same form as the potential except that the negative part has been reduced or cut off, and then we have the rectified current flowing in the positive direction through the telephone. This is changed into a varying direct current from the deformed oscillating current through the smoothing out action or filter action of the inductance of the phone and the capacity of the telephone cords. Figure 8 is drawn for a tube detector. If a simple crystal is used the current through the telephone is zero when there is no signal.

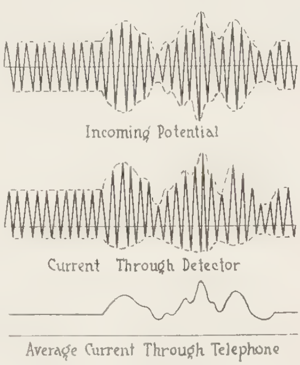


FIGURE 8.

It will be noted that when the radio current is not modulated, as from a tube, there is current through the telephone but it is constant current. A constant current produces no sound in a telephone. We hear nothing unless the radio current is modulated.

The theory and explanation applies to crystal detectors, vacuum tube detectors, or to any detector, which depends upon curvature of its characteristic.

137. Choppers or Tone Wheels. In the early days all transmission was by means of damped waves and all receivers were crystal receivers. Some of the more powerful transmitting stations began using high frequency generators and arc transmitters which generated current of constant amplitude and were known as C.W. stations. If a continuous wave is received by a crystal detector, as has been shown in the first part of the diagrams of Figure 8, the current through the telephone is constant and no noise or sound is heard. These stations transmitted the Morse code, dots and dashes. If the station is received on a crystal, the current through the phone rises to a certain value for a certain time for a dash, then dies to zero when the key is open and then rises to the same constant value and continues for a shorter time if a dot is sent. The only thing heard is a click at the beginning and at the end of the dot or dash. These clicks were confused with accidental noises and the code could not be read.

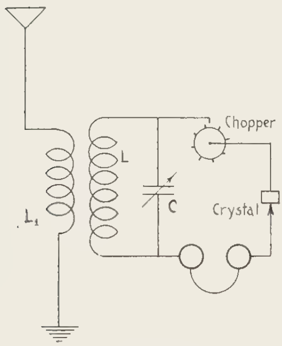


FIGURE 9.

In a convenient part of the transmitting circuit a key or wheel with contacts operated by a motor, was placed so as to open and close the circuit, perhaps 500 times per second. This "chopped" the continuous wave into small sections lasting 1/500 part of a second. The transmitting station was then said to be an interrupted continuous wave station, or an I.C.W. station. Thus the current in the phone increased to a certain value and then decreased to zero 500 times per second and produced 500 clicks per second, which produced a musical note. This musical note was heard as long as the transmitting key was held down.

Instead of chopping the signal at the transmitter, a key or wheel can be placed in the receiving circuit as in Figure 9. The action of the chopper and a crystal receiver is shown diagrammatically in Figure 10. At the present time a large percent of the trans-

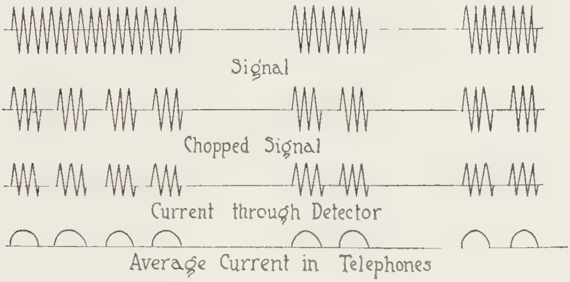


FIGURE 10.

mitting radio telegraphy stations use continuous waves. If one wishes to receive with a simple detector, such as a crystal, it will be necessary to use a chopper. Very few transmitters use choppers at the present time.

CHAPTER X

VACUUM TUBES

138. Introduction. The year 1915 is remarkable for two things. In February the first long distance telephone message was transmitted from New York to San Francisco, and in September the first radio telephone message was transmitted across the United States.

The success of these two epochs in speech transmission was due to the same thing—the three electrode vacuum tube.

Before 1915 it was not possible to telephone long distances because there was no means of amplifying speech which was free from distortion. It was possible to telephone from New York to Chicago but not from New York to San Francisco. In wire telegraphy electro-magnetic relays are used to control a local circuit which is capable of working a sounder, and this relay may work a circuit which transmits the signal a few hundred miles farther.

In telephony this relay or amplification can not be repeated with magnets or electromagnetic devices indefinitely, since after one or two amplifications the speech is distorted so much that it is unintelligible. The vacuum tube is a device which amplifies all frequencies with little distortion.

Historically the origin of the vacuum tube began with Edison. In 1884 Thomas Edison noticed that a third wire or terminal in an incandescent lamp became charged with a negative charge. In 1895 J. A. Fleming studied the Edison effect and found that terminals in tubes or bulbs in which there was an incandescent filament became negatively charged if there were no intervening objects between the terminal and the filament.

In 1904 Fleming patented the two electrode tube. In 1906 De Forest patented the grid, or the three electrode tube.

139. Two Electrode Tube. The two electrode tube consists of a filament which is surrounded by a plate. If the filament is a straight filament the plate is a hollow cylinder placed around the central filament. If the filament is V shaped or more or less flat, the

plate consists of two sheets of metal, one placed on either side of the filament. In general, a two electrode tube looks like the usual three electrode tube with the grid removed. The 280 and 281 rectifier tubes are two electrode tubes. Figure 1 is a 280 two electrode tube.

When the filament is heated the plate attracts the electrons if the potential of the plate is positive. When the potential is negative the plate repels the negative electrons. If the plate is connected to an alternating potential the electrons move to the plate during the positive half of the cycle only. Instead of an alternating current through the tube there is a flow into the plate and across to the filament. The two electrode tube was first used as a detector, since current flowed through the telephone which was in the plate circuit only when the signal was received, the principle being very much like that of the crystal detector. The two electrode tube was then a rectifying device used for detection in place of the crystal detector. It was about as efficient as the crystal and cat whisker, but was more reliable. It did not loose its "sensitive spot."

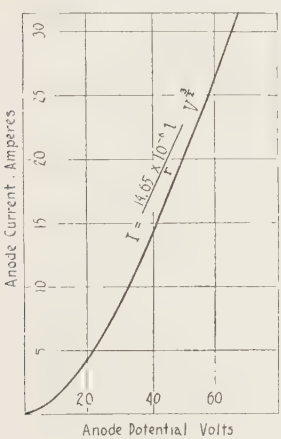


FIGURE 2.

FIGURE 1. A modern two electrode tube. This tube is a rectifying tube used to rectify alternating current. This particular tube rectifies both sides of the wave when connected to a central tap transformer. It has three connections but is a two electrode tube. It has no grid.

The characteristic curve of a two electrode tube is very much like the curve of a crystal detector. It may be used as a detector using the curved characteristic, or it may be used as a rectifier using the stopping of the negative current.

The current from a two electrode tube has been shown by Langmuir to obey the following equation: $I=f(V^{3/2})$. Figure 2 is a curve showing this relation.

140. Three Electrode Tube. The three electrode vacuum tube, triode, audion, or other names ending in "-on," or simply tube, for short, consists of an ordinary filament, as is found in small electric lamps such as automobile lamps, around which is placed the grid. This grid may consist of a coil of very fine wire, or it may consist of a screen or mesh made of fine wire. Around the grid the plate is placed. The plate consists of a sheet or cylinder of metal.

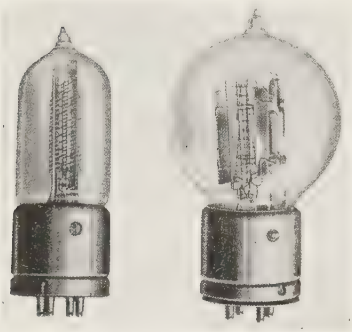


FIGURE 3. Western Electric tubes. The filament grid and plate can be seen in these tubes.

Figure 3 shows Western Electric tubes. In these tubes it is easy to see the filament grid and plate. Figure 4 also shows a cut out diagram of a modern tube. All tubes are of the same general construction. In many tubes the plate surrounds the grid and filament in such a way that one cannot see the construction.

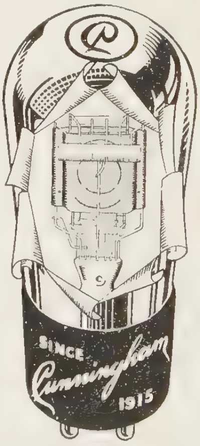


FIGURE 4. A drawing showing the outside of the plate of a modern tube.

When ordinary metals are heated up to a certain temperature, usually near white heat, they give off electrons. Figure 5 is a curve showing the relation of current to filament temperature.

In an ordinary tungsten lamp the electrons evaporate out of the filament and in a short time they fall back into the filament. In the audion, the plate is kept at a positive potential with respect to the filament and the electrons are attracted to the plate; then there is a constant stream of electrons from the filament to the plate, which means that there is a current flowing from the plate to the filament across the vacuum space of the tube.

The grid is made of very small wire and practically all the elec-

trons pass through the meshes of the grid, so that the grid current is very small.

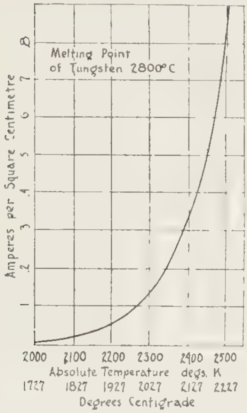


FIGURE 5.

141. Space Charge. As the plate potential is increased the current increases until all the electrons are used in producing the current. This increase is due to the space charge. Between the filament and plate there is a stream of electrons moving toward the plate. These electrons are charged negatively and repel the electrons near the filament. As the plate potential is increased the electrons move faster and the number in the space is diminished. This diminishes the space charge. Figure 6 shows the action of the space charge and the grid potential on the electrons. In this way the grid potential acts as a control of the plate so that a small change in the grid potential produces a large change in the plate current, therefore there is amplification.

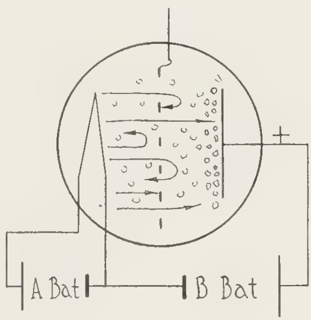


FIGURE 6.

142. Connection to Tube. The tube is usually diagrammed as in Figure 7. The loop represents the filament, a wavy line represents the grid, and a straight line represents the plate.

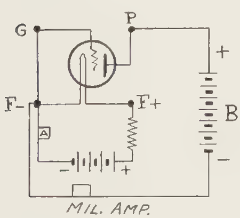


FIGURE 7.

A storage or dry battery of one and one-half, four or six volts or more, is connected as an A battery, to the filament with a controlling resistance in series. The plate is connected to a B battery of twenty-two volts or more. The negative terminal of the B battery is usually connected to the negative end of the filament. The grid is connected to the same negative terminal of the filament. *Make all connections* to the nega-

tive terminal of the filament, is a good rule to follow. If connections are made to both legs, there is danger of getting the B battery across the filament and destroying the tube. If the current in the plate circuit is measured as the potential of the grid is changed, it is found that the curve is as in Figure 8. The curve usually consists of three parts—a straight line in the middle and a short curved portion on each end.

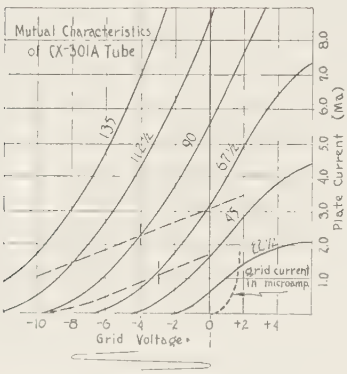


FIGURE 8.

Due to this change of the character of the curve, the tube can be used as a detector if it is worked on the lower curved portion of the curve, and as an amplifier if worked on the straight portion. As a general thing there is more or less amplification when there is detection.

The tube as now manufactured has four terminals, which fit into a special spring or clip socket. At one point on the base of the tube a short rod or bayonet extends and when the tube is pressed down fits into a groove in the socket. A slight turn to the right locks the tube, in the old fashioned spring socket. Place the tube on the table in an upright position with the locking projection or bayonet on the opposite side of the tube from you. Then the two front terminals of the tube are the filament terminals, the left one at the back is the grid terminal, and the one at the right back is the plate terminal. The sockets are usually marked F−, F+, *G*, and *P*, as in Figure 9. The standard base is convenient, but it has a disadvantage in that the capacity of the tube is rather great, and

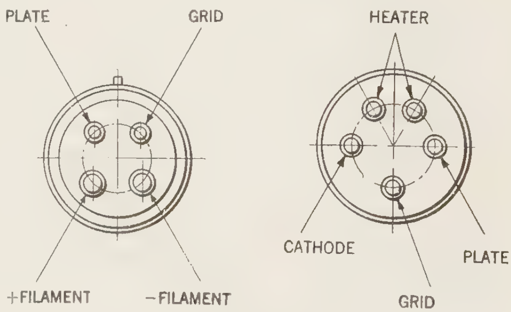


FIGURE 9.

in that the lead wires through the base are close together and there is danger of short circuit if the plate potential is high. Figure 9 also shows a five prong base.

143. Hard and Soft Tubes. Tubes as manufactured now are known as soft or hard tubes. The vacuum in soft tubes is not as good as in the hard tubes. Soft tubes are also known as gas tubes. In these a considerable amount of air or other gas is left in the tube. When the plate potential exceeds a certain amount in these soft tubes the plate current suddenly increases and a peculiar blue glow is seen between the grid and filament. This is caused by ionization by collision of the electrons with the gas atoms. Figure 10 shows a number of early tubes.

Soft tubes make good detectors but the adjustment of the grid and plate potentials for the best condition is rather critical. The 200A tube is a tube which has a trace of caesium in it. Hard tubes are always used when amplification is wanted.

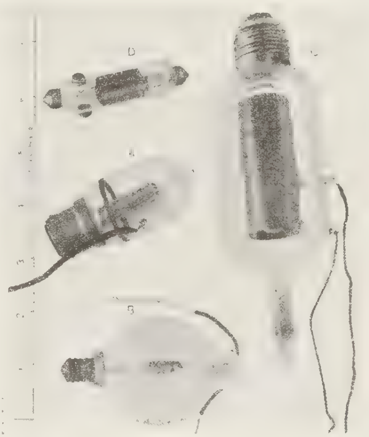


FIGURE 10.
A. Fleming valve C. Marconi "N" triode
B. De Forest "audion" D Marconi "Q" triode

At the present time, the most common tubes in use are the 201A tube, the 199 tube and the 200A detector tube, which are designed for direct current, and the 226 and 227 tubes designed for A.C. on the filament, the screen grid tube, and several power tubes. There are many other tubes used as power tubes and transmitter tubes. The general characteristics of all three electrode tubes are the same. The first three tubes mentioned above have thoriated filaments. The filaments are made of tungsten in which a certain amount of thorium or thorium oxide has been mixed when the tungsten was in the molten state. This thorium diffuses to the surface and when heated to a dull red heat, gives off electrons copiously.

In tubes in which the filament is pure tungsten the temperature of the filament must be raised to a white heat before the electrons

are "evaporated" out. Certain substances such as ordinary lime give off electrons at a low temperature. Some tubes have treated or coated filaments. A filament coated with ordinary lime will serve the purpose until the lime burns or drops off. Cheap tubes with treated filaments work well at first but soon lose their power of electron emission. The best treated or coated tube is liable to be injured if the filament is heated to a white hot temperature.

144. Tube characteristics. A tube characteristic or characteristic curve is a curve which shows the characteristic of the tube. A study of the characteristic curve will show how a particular tube operates.

In the operation of a tube we have, (1) the filament current, (2) the plate potential, (3) the plate current, (4) the grid potential, and (5) the grid current. All of these are more or less related one to the other. The filament current, plate potential and the grid potential are under our control. If either of the three is changed, the plate current and the grid current are, in general, changed also.

To obtain the characteristic, connections are made as in Figure 11. The filament current is furnished by a battery known as the A battery. The filament current is measured by the ammeter in the filament circuit. Instead of an ammeter to measure the current a voltmeter may be placed across the terminals of the filament and the filament voltage measured instead of the filament current. The normal or maximum filament current and filament voltage can be found from data furnished by the makers of the tube.

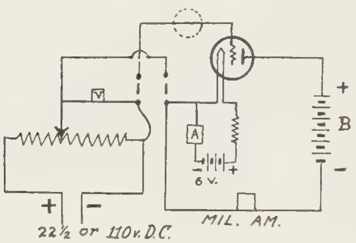


FIGURE 11.

The battery in the plate circuit is known as a B battery. The potential of a good B battery will remain constant. This potential can be measured once for all or it can be taken as the value marked on the battery if the battery is in good condition. The plate current is measured by means of the ammeter or milliammeter in the plate circuit. The battery in the grid circuit is known as the C battery. The value of the grid potential is varied by making connection to various

parts or taps on the battery so as to include one, two, or more cells, or by means of a potentiometer, as shown in Figure 11. The potential of the grid is measured by means of the voltmeter placed between the tap and the fixed connection. The grid current is measured by means of a microammeter or a galvanometer placed in the grid circuit in Figure 11.

There are four characteristic curves: the filament current–plate current, or filament characteristic; the grid potential–plate current, or mutual characteristic; the grid potential–grid current, or grid characteristic, and the plate potential–plate current, or plate characteristic. These are curves in which the first quantity named is plotted along the X axis as abscissa (along the horizontal axis) and the second is plotted along the Y axis as ordinates (along the vertical direction). Thus in the filament current–plate current characteristic filament current is used as abscissa and plate current is used as ordinate.

145. Filament Characteristic. To obtain the data to plot the filament current–plate current curve, the grid may be free, that is, it is not connected to anything, or the grid can be connected to the regular filament connection, Figure 7. A B battery of known potential $22\frac{1}{2}$ volts, say, is placed in the plate circuit and the values of the plate current are read on the milliammeter as the filament current or potential is changed by means of the rheostat in the filament circuit. The filament current is set to a certain value and the corresponding plate current is read. These readings are recorded, the filament current is changed to a larger value and the plate current read again. This operation is carried out until the filament current is the normal rated value. When this data is plotted a curve like the $22\frac{1}{2}$ volt curve in Figure 12 is obtained. A larger B battery can be placed in the plate circuit and readings taken again. When these readings are plotted a curve like the 45 volt curve is obtained. These curves show that the plate current is zero

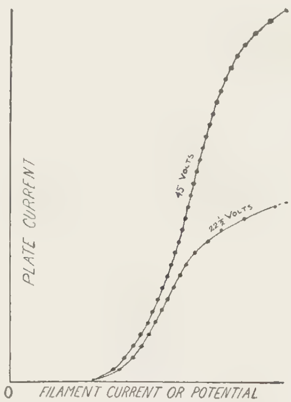


FIGURE 12.

until the filament current has reached a large percent of the normal value and increases as the current or temperature of the filament increases. They show that with increased B potential the plate currents start from the same point but rise to higher values as the B battery is increased.

This curve is really a curve showing the variation of current with temperature.

The shape of the filament characteristic can be explained in terms of the space charge. If a filament is heated as in the case of an ordinary incandescent lamp, electrons evaporate out of the filament but the space soon becomes filled or saturated and other electrons are repelled by this space charge and fall back into the filament. As many fall back as evaporate out. A closed space over water soon becomes saturated with water vapor and as many molecules of water fall back as evaporate out. The action is the same with a filament when there is no charged plate. When the plate is charged positively and the temperature of the filament is low there are few if any electrons evaporated, and if there are any they are attracted to the plate almost instantaneously and there is practically no space charge. There are no electrons in the space between filament and plate. As the temperature rises the number of electrons evaporated out increases and the current increases with the number. As the number increases, although any one electron may move very fast, there are always an appreciable number of electrons in the space between filament and plate. Figure 6 illustrates this space charge. This has its effect and repels the evaporating electrons which increase more and more until the number is such that the current becomes nearly constant, independent of temperature. This is the upper bend on the curve. If a higher potential is used on the plate the curves are nearly the same for low temperatures, but the current increases to a higher value before the space charge hinders the current appreciably.

If the grid is at the same potential as the filament the space between filament and grid is filled with a space charge. Making the grid positive moves these electrons toward the grid to the point where they are accelerated by the plate potential and thus the plate current is increased. When the plate potential is high the electrons are accelerated by the plate potential even if the grid is negative enough to keep the electrons from hitting it; i.e., when the grid current is zero.

146. Mutual Characteristic. In the grid potential plate current characteristic or mutual characteristic, the filament current is held at some fixed value, generally the normal value as given by the manufacturers of the tube. The plate potential is kept constant, the potential of the grid is changed by steps and the corresponding plate current is read. The connections are made as in Figure 11. While taking this data the microammeter in the grid circuit can be read at the same time and data for the grid characteristic can be obtained.

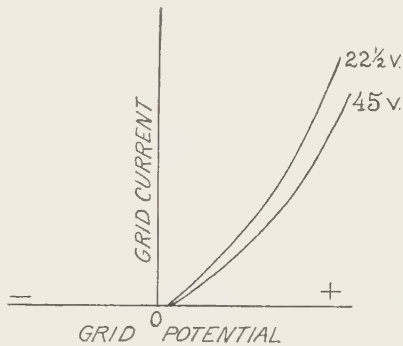


FIGURE 13.

It is a great convenience if a reverse key is placed in the grid circuit as shown in Figure 11, so that the potential of the grid may be made both positive and negative. The potential of the negative terminal of the filament is usually taken as zero. The reverse key should be turned so as to make the grid negative and reduce the plate current to zero and then gradually change the potential until the plate current becomes constant taking reading at regular intervals. When this data is plotted we have a curve like Figure 8. If the plate potential is changed in steps and the data taken we get a series of curves which are more or less parallel. It will be noted that these curves move toward the left as the plate potential is increased.

147. Grid Characteristic. If the readings of the microammeter in the grid circuit of Figure 11 are read and plotted as ordinates against the grid potential as abscissas we have the grid potential—grid current curve, or grid characteristic. The absolute value of the grid current is of no particular value. The position of the origin of the curve and its general shape is of importance. Galvanometer readings may be plotted instead of absolute values of the current. Two curves are shown in Figure 13. It will be noted that these curves start from practically the same point and move toward the right.

148. Plate Characteristic. The plate potential plate current characteristic curve can be obtained by using the connections given in Figure 11. The potential of the grid can be set to a particular value and then the plate current can be read by the meter in the plate circuit with various values of the B battery; i.e., $22\frac{1}{2}$, 45, $67\frac{1}{2}$, 90, etc., volts, and the values plotted as in Figure 14. Instead of taking new readings the values can be taken off of the mutual curves if they have been constructed. The potential of the grid in the mutual characteristic curve can be assumed to be zero and the values of the current read off at the points where the various curves cross the vertical line $E_g = 0$. These values can be plotted as in Figure 14

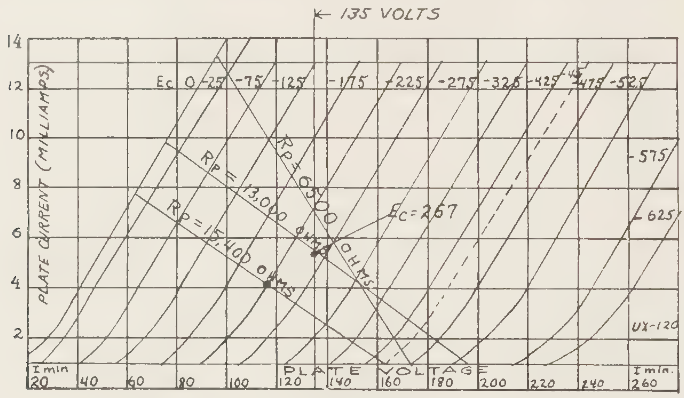


FIGURE 14.

and we have the curve $E_c = 0$, then the values can be read off where the grid potential is another value, $E_c = -25$ volts, and we have data for the plate characteristic $E_c = -25$.

Figure 15 is a Jewel instrument set up for taking the characteristics of a tube. The connections are given diagramatically in Figure 16. With this apparatus all the curves can be taken. Changes from one connection to another are made with switches.

149. Use of Characteristic Curves. The plate characteristic is convenient when computing the power output of power tubes.

The mutual characteristic is the one usually referred to. It will be noted that the curve consists of three parts, a curved portion at the bottom, a nearly straight portion and usually a curved

portion at the top. It may be impractical to run the curve high enough to obtain the curved upper portion.

FIGURE 15.

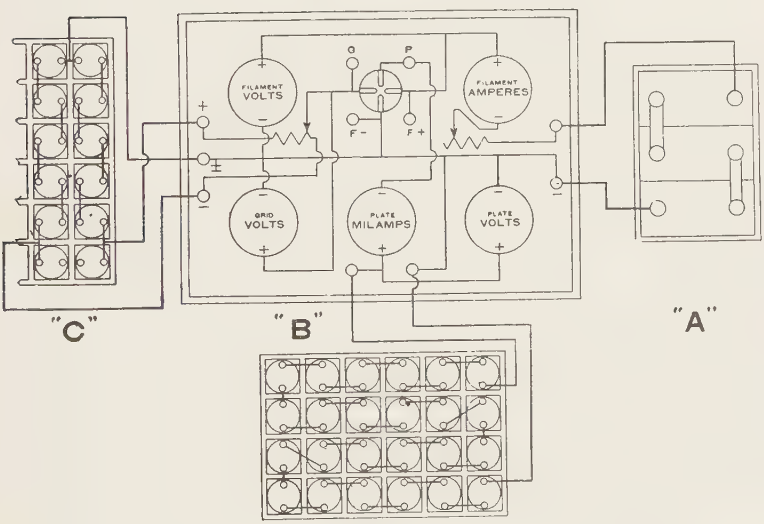


FIGURE 16.

The lower curved portion, together with the lower curved portion of the grid characteristic, are used to explain detection and the straight line portion is used to explain amplification. A detector tube should be adjusted by means of grid potential; i.e., C battery, or grid condenser and grid leak so as to operate on the lower curved portion of the curve. An amplifying tube should be adjusted to operate on the straight line portion of the curve, between limits such that there is no grid current, and such that the lower curved portions of the curve are avoided.

150. Reactivation of Tubes. It has been found that when filaments are subjected to a vapor or gas that they seem to loose their property of giving off electrons. The filament has been "poisoned." This poisoning seems to be an oxidation or coating of some kind which forms over the filament.

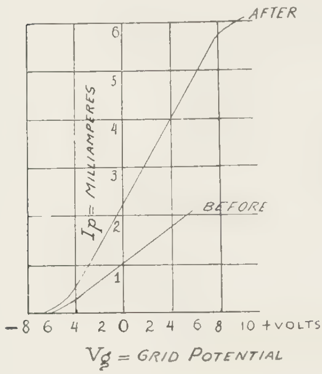


FIGURE 17.

If this coating can be removed then the filament renews its property of giving off electrons. In the thoriated filament tube the thorium is burned or evaporated off if the temperature is too high.

When a tube is "poisoned" the first thing is to remove the poison and then to renew the thorium at the surface.

The tube is first flashed at a high temperature. This removes the "poison" also the thorium from the surface. Then the tube is burned at a temperature above normal without plate voltage until the thorium which is mixed with the tungsten can diffuse to the surface. The B battery should be disconnected from the plate of the tube.

The general rule is to flash the tube at a voltage three times the normal voltage for thirty seconds or one minute. Then the tube is aged for two to ten minutes at a voltage 50% above normal voltage. For a 201A tube, the tube is flashed at 15 volts and aged at 7.5 volts. It is immaterial whether the voltages are D.C. or A.C.

Figure 17 shows the plate emission before and after reactivation.

CHAPTER XI

VACUUM TUBE CONSTANTS

151. Introduction. The three electrode vacuum tube has three important constants. These are the amplification constant, μ, the mutual conductance, G_m, and the resistance of the tube, R_p. These so-called constants depend to some extent on the filament temperature, plate potential, and the grid potential, but as tubes are usually operated their values do not change much. For practical purposes they are constant. These constants can be measured in various ways. It is instructive to determine them from the characteristic curves.

152. Three Halves Power Law. In the section on the two electrode tube it was stated that the plate current obeyed the law

$$I=f(V^{3/2}) \text{ or } I=AV^{3/2}.$$

In the three electrode tube the potential, V, is made up of the sum of the potentials E_p and E_g where E_p is the plate potential and E_g is the grid potential and μ is the amplification constant. Then $I_p=A(E_p+\mu E_g)^{3/2}$. This is the theoretical equation and the curve is given in Figure 2, Chapter X.

153. Actual Curves. Actual curves of three electrode tubes do not follow this law exactly, one reason being the temperature of the filament is not the same at all points. The ends connected to the lead-in wires are cooled by conduction. In actual cases the curves consist of three parts—a lower curved portion, a central portion which is nearly straight, and the upper bend at saturation. If several grid potential plate current curves are run with different plate potentials the central portions are not only nearly straight but nearly parallel.

The central portions may be said to be a family of straight lines. This is nearly true for tungsten filament tubes. Figure 1 shows the grid potential plate current curves, using a 201 Radiotron amplifying tube. The central portions for all purposes are straight and are parallel. Treated or thoriated filament tubes such as 201A tubes do not give curves which are exactly straight lines, but by drawing on the imagination the theory can be ap-

plied to them. Figure 8, Chapter X, is a set of curves of a thoriated filament 201A tube.

154. Calculation of Constants from Curves. Assuming the straight curves to be straight and parallel as in Figure 1 the equation of the current is $I_p = A + B(E_p + \mu E_g)$. This equation is the equation of a family of straight lines. In Figure 1 the curved ends are disregarded and the curves are assumed to follow the dotted lines at the ends.

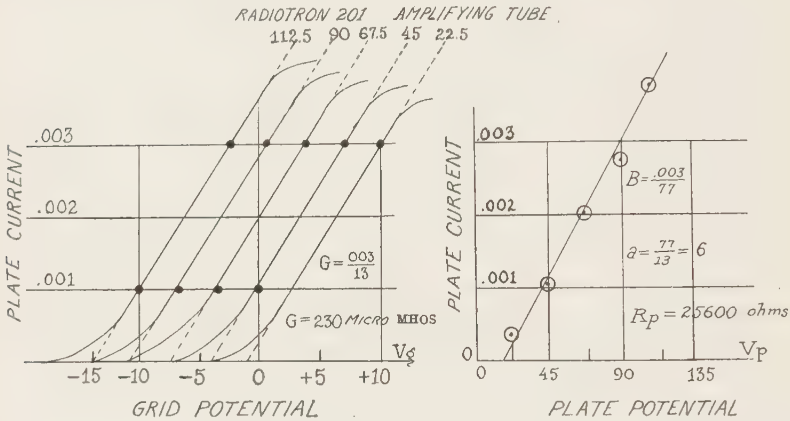


FIGURE 1.

This equation shows that the current at any time or condition depends upon both the plate potential, E_p, and the grid potential, E_g. If in the equation the grid potential, E_g, is changed one volt there is a certain change in the plate current, I_p. This change in plate current will be the same if we change the plate potential μ volts, where μ is the amplification constant. Thus if μ is seven volts the current is changed a certain amount by changing the grid one volt or by changing the plate potential seven volts. One volt on the grid is equal to μ volts on the plate.

155. Mutual Conductance. If we assume that the plate potential, E_p, is constant and find the change of the plate current when we change the grid potential E_g, we have by differentiation,

$$dI_p = B\mu dE_g \quad \text{or} \quad dI_p/dE_g = \mu B = G_m.$$

The expression $dI_p/dE_g = \mu B = G_m$ is read the rate of change of the

plate current, I_p, with respect to the change of the grid potential, E_g, is equal to the amplification constant, μ, of the tube, times a constant, B, and this product is equal to the mutual conductance of the tube, G_m. The expression shows how the current in the plate circuit changes when the grid potential changes.

If we refer to Figure 1 we see that in order to change the plate current three milliamperes or .003 amperes, the grid potential must be changed 13 volts. Then $G_m = .003/13 = .000230$ or 230 micromhos. Since resistance $R = E/I$, G_m is the reciprocal of resistance, or G_m is a conductance. It is called mutual conductance, since it is the effect in one circuit caused by a change of potential in another circuit. The mho is the reciprocal of the ohm.

156. Tube Resistance. If we consider the grid potential to be constant, as in the plate curves of Figure 1 and differentiate the equation, we get $dI_p = BdE_p$ or $dI_p/dE_p = B$. This is a conductance, and since both current and potential refer to the plate, it is the plate conductance. The reciprocal of this is the plate resistance of the tube, or simply the resistance, R_p, of the tube. From the plate characteristic, Figure 1, we see that in order to get a change of .003 amperes it is necessary to change the plate potential 77 volts. The resistance, $R_p = 77/.003 = 25600$ ohms.

157. Amplification Constant. Since $G_m = \mu B$ we have the amplification constant of the tube, $\mu = G_m/B = 77/13 = 6$. Thus it is possible to determine the constants of the tube by taking the mutual characteristics for several plate voltages then drawing the plate characteristics and then taking the slopes of the lines.

Since these lines are straight lines in Figure 1 the slope or the value of dI/dE is the same at every point. If the lines are curved slightly then the slope changes from point to point a little and the values of the tube constants change with conditions.

In tables the values of the constants are given under specified conditions. In most of our calculations the assumption is made that the curves are very nearly straight lines. The calculations are made and then the information is given that the distortion is not over a certain amount.

The mutual conductance, $G_m = \mu B = \mu/R_p$. The mutual conductance is equal to the amplification constant divided by the resistance of the tube. The mutual conductance tells more than the amplification constant. A tube with a high amplification constant

and an enormous resistance is not a good tube. A high amplification constant and a low resistance is wanted.

158. Physical Structure and Constants. It is beyond the realm of this book to discuss the manufacturing methods of controlling the constants of the tube produced, but it might be mentioned that the amplification constant can be increased by making the distance between grid and plate large. But the resistance is increased when this distance is increased. As a rule, high mu tubes are high resistance tubes.

The constants of the tube are changed by changing the filament current. If the curves for a tube are run, using normal filament current, and then the curves are run again with diminished filament current, 10% below normal, say, then the constants will be different. The amplification constant, μ, will not decrease much. It may even increase, but the mutual conductance will be much diminished and the resistance R_p increased.

The slope of the plate characteristic is the conductance of the tube. The reciprocal of this slope is the resistance of the tube. The slope of the mutual characteristic is the mutual conductance. The reciprocal of the mutual conductance might be called the mutual resistance of the tube. The amplification constant of the tube is the ratio of the slopes. It might be well to call attention to the fact that resistance here is defined as $R = dE/dI$. Resistance is generally defined as $R = E/I$. Both definitions are the same if the resistance is constant.

159. Power Amplification Constant. The power amplification constant of a tube is the output of the tube divided by the input. This is sometimes represented by η, the Greek letter eta. $\eta = E_p I_p \cos \theta/(i_g E_g)$. This at times is hard to calculate and becomes practically meaningless. This is because the grid current, i_g, often becomes very small. If the grid battery or C battery is adjusted for good amplification, the grid current is zero. This means, of course, that the D.C. in the grid is zero. When this is true the A.C. is simply that which flows through the capacity of the tube and thus it is very small. Then in calculating the value of η we see it will be very large. In fact, η has no meaning which is worth anything. Often we read of the amplification of a tube being very large. Usually power amplification is what is meant.

160. Power and Current Amplification Rating. It is much better in speaking of power to give it in terms of watts or milliwatts per volt squared input. This will be seen later to depend upon the load or the device to which the tube is connected. Current amplification constant is also somewhat ambiguous. It should be given in terms of amperes output per volt input.

161. Capacity of Tube. Another important constant of a tube is its capacity. Between the grid and the plate of a tube there is a certain capacity. The tube is a condenser, one plate being the grid of the tube and the other the plate of the tube. This capacity can be measured the same as that of any other small condenser. The capacity cannot be determined from the characteristic curves.

162. Measurement of Tube Constants. The measurement of the constants of a tube leads to a better understanding of the constant. If a tube is connected as in diagram, Figure 2, to a potentiometer, *abc*, made of two resistance boxes, and an alternating potential is applied to the terminals *ac* of the boxes, then if the point *b* is considered to be zero potential, the potential of the point *a* will rise and fall, and at the same time the potential of *c* will fall and rise. Raising the potential of *a* raises the potential of the grid and increases the plate current. Lowering the potential of *c* lowers the potential of the plate and diminishes the plate current. If the potential of *a* is raised and the potential of *c* is lowered the proper amount, the plate current will be constant. A telephone in the plate circuit will indicate that current by a minimum sound.

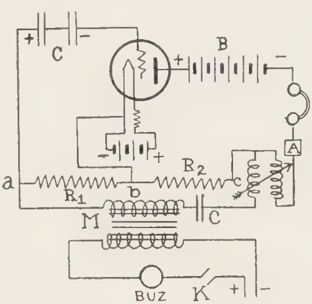


FIGURE 2.

The effect on the grid is just equal to the effect on the plate. We have defined the amplification constant as being dE_p/dE_g, but the changes of potentials are proportional to the resistances, and then $\mu = R_2/R_1$. The variometer and the condenser, *C*, can be omitted, the connections being like those in Figure 4, with the key, *K*, open.

163. Measurement of the Mutual Conductance of a Tube. In Figure 3 with the key, K, open, the potential of the grid is zero, that of the negative filament, and the plate current is measured by the milliammeter, A. The current flows from right to left through the meter. With the key, K, closed the current from the battery, C, flows from left to right through the milliammeter, the grid current being zero. If the resistance, R_1, is adjusted so that the meter reads the same whether the key is closed or not, then we have the change of the plate current, dI_p, equal to the current from the battery, which is equal to dE_g/R_1. dE_g is the potential of the grid with the key closed. Then $dI_p/dE_g=1/R_1$. By definition $dI_p/dE_g=G_m$, or G_m is equal to the reciprocal of the resistance R.

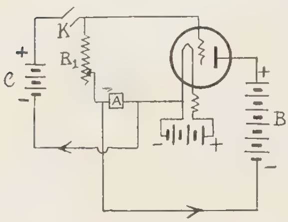


FIGURE 3.

164. Measurement of Plate Resistance. The plate resistance can be measured with the same apparatus as that used in finding the amplification constant if a resistance, R, is placed in the plate circuit. Figure 4 is the same as that of Figure 2 except the negative filament can be connected to the negative end of the B battery through a resistance, R, by closing the key, K. In Figure 4 a variable mutual inductance, a variometer, can be placed as in Figure 3, so that corrections for phase angle can be made. A blocking condenser, C, also can be placed in the A.C. circuit. The minimum sound in the telephone is much better with the variometer in the circuit. Consider the plate circuit through the resistance, R, with K closed. The potential of the point, d is $(R/(R+R_p))E_p=(R/(R+R_p))\mu E_g$. Considering the A.C. circuit through R_1 and R_2 we have the potential of c, which is the same as the potential of d, if the phone has negligible resistance, equal to

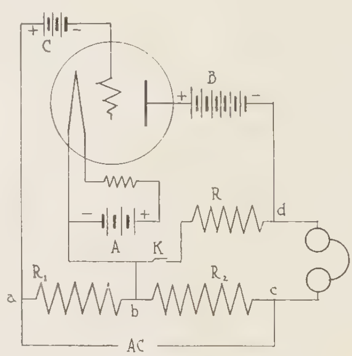


FIGURE 4.

FIGURE 5.

$(R_2/R_1)E_g$. Then $\mu(R/(R+R_p)) = R_2/R_1$, and $R_p = R((\mu R_1/R_2)-1))$. R_1 and R_2 are not the same values as those obtained in measuring the amplification constant.

165. Apparatus for Measurement. Figure 5 is a General Radio Co. 361B V. T. Bridge for the measurement of the constants. By convenient switches the connections can be changed to those of either Figures 2, 3 or 4.

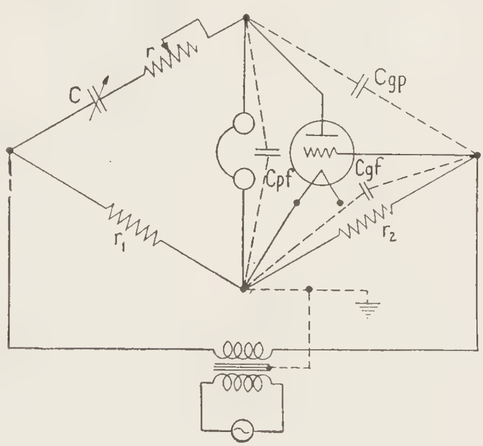


FIGURE 6. A Bridge Method of Measuring Grid-Plate Capacity. Nema Hand-Book.

Diagram, Figure 6, gives the connection for measuring the capacity of a tube. This will be seen to be the simple method. ("Experimental Radio," p. 25, 78.)

CHAPTER XII

THE VACUUM TUBE USED AS A DETECTOR

166. Two Methods of Detection. The three electrode vacuum tube can be used as a detector in two different ways. Detection can be had by using the curvature at the foot of the mutual characteristic curve, or detection can be had by using the curvature of the grid characteristic curve. The first method is sometimes called detection by plate current rectification, and the second is called detection by grid current rectification. This last is sometimes spoken of as grid condenser detection.

167. Detection by Plate Current Rectification. In the mutual characteristic curve, if the plate potential is rather low, 16 to 45 volts, the point of greatest curvature is not far from the point where the grid potential is zero, the potential of the negative filament being considered to be zero. The theory developed in Chapter IX on detectors for the crystal detector applies here as well as to the crystal The action of both depends on the curvature of the curve.

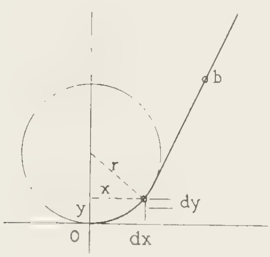


FIGURE 1.

168. Geometrical Method of Explaining Detection. In the theory for the crystal detector we applied Taylor's expansion. Here we shall apply a geometrical method. Let the curve in Figure 1 represent a mutual characteristic curve, the Y axis representing plate current, I_p, and the X axis representing the grid potential, E_g. Assume that the lower curved portion of the grid characteristic curve is part of the circle whose radius is r. Let x represent the grid potential, zero grid potential being at zero, the point of tangency of the circle to the X axis. Then the plate current is represented by y. From Figure 1, $x^2+(r-y)^2=r^2$, then $r-y=\sqrt{r^2-x^2}$. Extracting the square root and neglecting higher powers $r-y=r-x^2/2r$, or $y=x^2/2r$, and $dy/dx=2x/2r$ and $(dy^2/dx^2)=1/r$ or $d^2y=(dx)^2/r$. Let x equal the grid potential, y equal the plate current steady value.

If dx represents the change of the grid potential or an alternating potential, dy is the change of the plate current. This will be constant if the curve is a straight line, and d^2y will be zero if the curve is a straight line.

If we assume that dx is a sine function, or that the grid potential is alternating at radio frequency, then y is the direct current through the telephone, dy is the alternating current through the phone. This will produce no effect on the phone at audio frequency, the average value will be zero; d^2y is the detected current through the telephone which gives an audible tone in the telephone. Since $d^2y = (dx)^2/r$, we have the detected current, $i = e^2/r$. Since dx is equal to e, the alternating E. M. F. on the grid.

It will be noted that this detected current is proportional to the square of dx, the signal voltage, and is inversely proportional to the radius. The reciprocal of the radius is a measure of the curvature of the curve. The signal is proportional to the square of the signal voltage and proportional to the curvature. This agrees with the value $i = (e^2/4)(d^2I_p/dV^2_g)$ which was derived in Chapter IX.

To obtain good loud signals in the phone, the signal voltage should be amplified at radio frequency to a reasonable value and the detector should be worked at the point of greatest curvature. Since the detected current is proportional to the square of the signal voltage, a radio frequency amplification of 10 is equal to an audio frequency amplification of 100.

It will be noted here that is is possible to over-amplify at radio frequency. Suppose the signal voltage is amplified so that the positive limit on the curve is on the straight line portion at b, perhaps, and the negative limit is near zero or to the left of zero, then the detected current will be due to the curved portion only. If the detector is used in a radio phone receiver, the rectified current will be distorted due to the "cut out" on the straight line portion of the curve. With the ordinary average tube the signal voltage should not be more than ½ volt, certainly not more than 1 virtual volt.

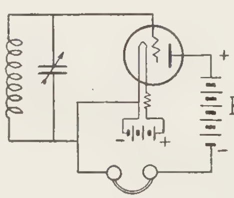


FIGURE 2.

Figure 2 shows the connection for a tube receiver. Figure 2,

Chapter IX, illustrates the detection using a tube assuming the signals are from a damped wave station, spark station. The first line represents the signal potential on the grid of the tube, the second the current in the plate of the tube, the third line the average current through the telephone. Detection with a tube and crystal are exactly the same except when a tube is used the current through the plate and phone has a constant value greater than zero. The inductance of the phone and the capacity of the phone cords smoothing the high frequency current out into the smooth positive constant current. Note that the current in the phone is increased and causes one click in the phone for each group of waves, remembering that each group of waves is sent out by one spark in the transmitter, the tone heard is the tone of the spark in the transmitting station. It has been found that a pitch of about 1000 is the best pitch for a spark station. The tone is high enough not to be confused with static. For M. C. W. the action is similar to that of Figure 7, Chapter IX. Figure 3 shows how the plate current is increased when the grid is excited by a signal.

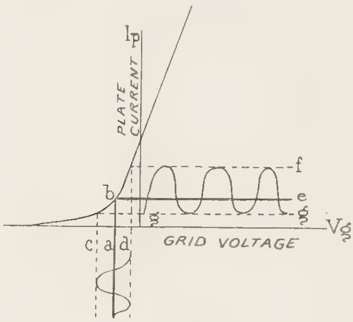


FIGURE 3.

169. Grid Current Curve Detection. The method most often used for detection with a tube is the grid current rectification method. In order to use the grid current curve it is necessary to use a grid condenser with grid leak.

If the grid characteristic is plotted on the same sheet of paper with the grid potential plate current curves, Figure 4, it will be found that the grid current starts from a point near zero and curves upwards very much like the plate current. The grid potential at the point of greatest curvature corresponds to a point on the plate current curves which is for all practical purposes a straight line. The average potential of the grid must be more positive for grid current rectification than for plate current rectification. Figure 5 shows grid characteristics of the common tubes in use.

It may be well to remember that the grid current, as well as the plate current, is due to electrons. The grid may be enough negative to keep electrons from striking the grid, but not enough negative

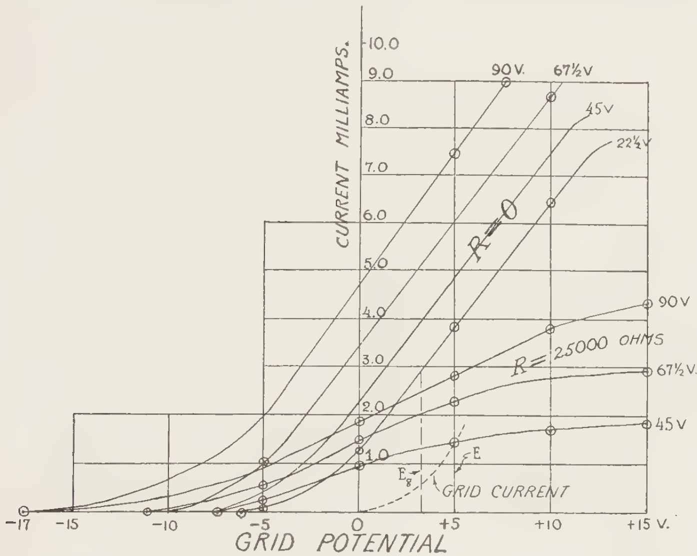


FIGURE 4.

to keep all the electrons from passing through the meshes between wires. The grid current becomes zero before the plate current becomes zero as the grid potential is made more and more negative.

In some gas tubes the grid current may reverse and give a negative current. This is due to positive ions in the tube. The gas becomes ionized, which means that an electron has been knocked out of a gas atom or molecule and then we have a positive ion, a positively charged atom or molecule.

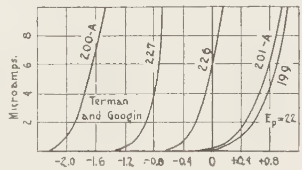


FIGURE 5.

If a grid condenser is connected in the grid circuit as in Figure 6, the grid, and therefore the grid condenser, becomes negatively charged if electrons strike the grid. We assume that there are no positive ions in the tube. If the condenser has perfect insulation

these electrons can not escape, and the condenser and grid become more negative as the electrons strike the grid. This will keep up until the grid becomes enough negative so the electrons do not strike, and the potential will be that value which on the curve corresponds to zero grid current. If the average potential is not absolutely constant but varies due to outside causes, the grid may become positive at times and more electrons striking the grid make it more negative. This may be enough to make the grid sufficiently negative to stop the plate current. A grid condenser alone will not work. A high resistance of about a megohm or more is placed across the condenser. This gives a path for the electrons to escape so that the grid potential does not become too much negative. When a steady state has been reached the potential of the grid will be negative with respect to the filament by an amount of i_gR where i_g is the grid current and R is the resistance of the grid leak. This potential should correspond to the point on the grid current curve where the curvature is the greatest.

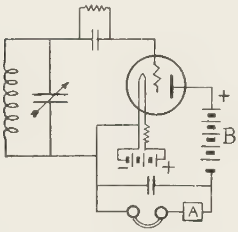


FIGURE 6.

If one has the mutual characteristic curve and the grid characteristic curve both plotted on the same paper, the reading of a milliammeter in the plate circuit, together with the curve, will show the average grid potential.

If, due to a signal, the potential of the grid varies about the average value, then, due to the fact that the characteristic is curved, more electrons will strike the grid during the time it is positive, and this increase of electrons will not be balanced by the diminution of electrons when the grid is negative with respect to the average value.

If the characteristic is straight, the two effects will exactly balance each other, the average value of the grid current will be constant and the average grid potential will be constant. Due to the curvature of the grid characteristic, the grid current is increased and the average negative potential of the grid is more negative, because this current must flow through the grid leak resistance, R. Due to the change of the average potential of the

grid, the plate current is diminished. This will give a click or sound in the telephone. Due to the fact that the tube is also an amplifier, the sound in the telephone is increased, Figure 7 shows the action of a grid condenser when used as a detector. The first line beginning at the bottom and reading to the left and up in figure 7 represents the signal potential applied to the grid. The second line is the potential of the grid. The grid potential is made up of the signal potential and the negative effect of the increased grid current. The third line shows the plate current and the fourth the average current through the phone.

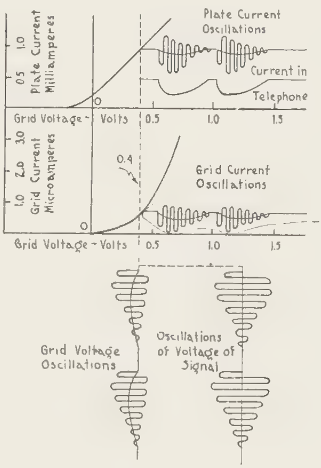


FIGURE 7.

If the plate current characteristic is curved, the two curves will act in such a manner as to tend to neutralize each other. The grid curve tends to diminish the plate current and the plate current curve tends to increase the current. This might take place if the plate potential was a few volts negative, one or five volts, perhaps, the two curves being almost identical.

The proper adjustment is usually found by trial. The usual condenser is about .00025. The impedance of the condenser, 1/C, should be small, and the capacity should be large compared to the capacity of the tube. The following table gives values for ordinary tubes.

The grid leak should be small enough to let the condenser recover the average value quickly, but large enough not to carry the signal. The time of recovery must be short compared to signal variations, and long compared to the radio frequency. The drop, i_gR, together with the "grid bias" must keep the average potential at the point of greatest curvature. The grid bias, or C battery, is a battery of a few volts placed in the grid circuit to give the grid a negative potential.

DETECTOR CHARACTERISTICS OF DETECTOR TUBES.
FOR WEAK SIGNALS, 0.1 VOLT OR LESS ON GRID.

Tube	*Plate voltage*	*Mu*	*Grid connection*	*V_g, Det. voltage Const.*	*Grid leak*	*Grid Condenser*
12	22–45	6	−F	0.27	8.0 Meg.	.000318 Mf.
199	45	6	−F	.5	1.5	.000255
201A	45	9	−F	.47	3.2	.000212
240	135	30	−F	.47	3.2	.000212
120	45	3	−F	.45	1.67	.000255
171A	45	3	−F	.28	7.20	.000160
112A	45	8	−F	.26	5.8	.000212
226	45	8	Cath.	.29	1.6	.000212
227	45	8	Cath.	.23	7.8	.000318

170. Detection with Gas Tubes. Soft tubes or gas tubes—tubes which have not been evacuated to a high degree—were originally used as detectors. Gas tubes make excellent detectors but are very erratic and take a great deal of coaxing. They depend upon the fact that at certain potentials the plate current changes very rapidly. The curves have kinks at certain potentials while the curves for hard tubes are straight. This is due to ionization potentials. At certain potentials the electrons acquire velocities high enough to knock electrons out of the gas molecules and the plate current suddenly increases. Since the potential is $E_p+\mu E_g$, the variation of the potential of the grid due to signal voltage may give this increase if the plate potential, E_p and average potential of the grid, E_g and the amount and kind of gas is just right.

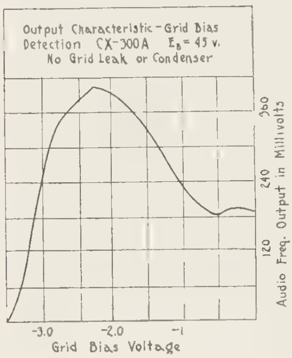


FIGURE 8.

The detector tube, Radiotron 200A, contains caesium. Gas tubes usually are rather noisy, due to the gas. Figure 8 shows the output characteristic of a 200A radiotron tube plotted against grid bias voltage.

171. Detection by Grid Rectification; Theory. The following is a simplified statement of the action of the grid condenser and grid leak. It will be seen that the capacity of the condenser does

not appear in this, it being assumed that the values are such as to give optimum results. The curvature of the curve depends upon the point of action, or the average grid potential. This depends upon the grid condenser and grid leak and upon the C battery.

The change of the grid current is proportional to e^2/r where e is the signal potential and r is the radius of curvature of the curve. This change is the same as in plate current detection (see paragraph 168).

If we let E_g be the average grid potential and assume that the plate current, I_p, falls on the straight line part of the characteristic curve, Figure 4, then the detected grid current is

$$i_g = \frac{e^2}{4r} = \frac{e^2}{4} \text{ (curvature)}.$$

The average grid potential,

$$E_g = (E - i_g R) = \left(E - \left(\frac{e^2}{4r}\right) R\right).$$

In Figure 4 we shall assume that the grid circuit in Figure 6 is connected to the positive filament instead of to the negative filament making the potential, E_g, five volts positive. Then the average potential of the grid will be less than this, due to the grid current flowing through the grid leak resistance. This $i_g R$ equals about two volts, making E_g about three volts as indicated in Figure 4.

The plate current,

$$I_p = A + B(E_p + \mu E_g) = A + B\left[E_p + \mu\left(E - \frac{e^2}{4r}\right)R\right]$$

$$= A + B(E_p + \mu E_g) - B\mu\frac{e^2}{4r}R.$$

Where, E_g = average grid potential and $e = e_0 \sin \omega t$ = change of grid potential. Change of plate current $= B\mu(e^2/4r)R$.

The audio signal is proportional to $B\mu$, the mutual conductance; to e^2, the square of signal potential; to $1/r$, the curvature of the grid characteristic, and to R, the resistance of the grid leak.

This will be true for the first signal. If the resistance R is infinite the tube will not recover and the second signal will be faint, since the operating point has changed from the optimum point. The resistance, R, must be small enough to let the tube recover from an intense signal. If the resistance is large it perhaps will detect ordinary signals, but a crash of static will "paralyze" the tube for a time.

172. Heterodyne Detection. At the present time most of the radio telegraph stations use continuous wave generators of some form or other. Very few of these take the trouble to interrupt by chopper or other means. The usual method of reception is by the heterodyne method, in which the incoming signal is heterodyned with a local generator, the frequency of which is near that of the received signal. One method is to use a detector such as a crystal detector and a local oscillator. At present the method usually used is a detector tube connected to one of the many circuits which will oscillate. In this case the tube is a generator, a detector, and also an amplifier. The circuit may be that of Figure 9. This will be seen to be a regenerative or oscillating circuit of Chapter V.

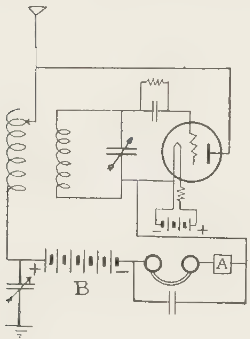


FIGURE 9.

It is well known that if two audible frequencies such as from two tuning forks which are nearly in unison are heard, there is a periodic swelling of the sound. Beats are produced, the frequency of which is the difference of the two frequencies. A tuning fork making 100 vibrations and another making 101 or 99 vibrations per second will produce one beat per second.

Two high frequency stations, one making 1,000,000 vibrations per second, and another making $1,000,000 \pm 1,000$ per second will make 1,000 beats per second. The beats are audible, while the million vibrations are not. Figure 10 represents the signal as well as the local oscillation. The resultant frequency is proportional to the difference of the frequencies. If the resultant wave is plotted as in the figure, we find a wave whose frequency is the difference of the frequencies.

There is also a frequency which is proportional to the sum of the frequencies. Since this is out of the audible range we are not concerned with it. Remembering that if either frequency is detected the result is an increase of D.C. current, which is proportional to e^2 where e is the intensity of the signal. The frequency of these are so great that the D.C. is constant in value. The amplitude of the resultant wave changes from the difference of the amplitude to the sum of the amplitudes, or from values proportional to e_1-e_2, to e_1+e_2. The amplitude of the beat wave is proportional to e_1+e_2. The detected E.M.F. is then e_1+e_2. The detected current is proportional to e^2g where e_g is the signal intensity. (See theory of detectors.) Therefore the detected currents are proportional to $(e_1+e_2)^2$. This is $e_1^2+2e_1e_2+e_2^2$. Since $e_1=E_1 \sin \omega t$ and $e_2=E_2 \sin \omega_2 t$, both being high frequency E.M.F.'s, the square terms give a constant current through the phones. These are detected currents which cause a constant current through the phones and produce no sound. The middle term gives a component through the phones which changes in intensity at the beat frequency, since $E_1 \sin \omega_1 t \; E_2 \sin \omega_2 t = E_1E_2 \, [\sin (\omega_1-\omega_2)t + \sin (\omega_1+\omega_2)t.]$ The beat frequency, $(\omega_1-\omega_2)$ can be made any desirable value from zero up to frequencies out of the audible range simply by changing the condenser in the oscillating receiver circuit. The tone can be changed simply by changing the frequency of the local oscillator.

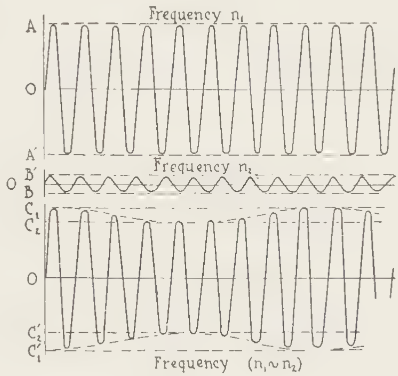


FIGURE 10.

In Figure 11 we have attempted to illustrate the heterodyne detection. Let e_2 represent the incoming signal, the mutual characteristic supposed to be an arc of a circle, i.e., curvature constant. If ordinary detection were used the detected current would be represented by the increase of the plate current at B. This would be small and moreover would be constant. Let e_1 represent the received E.M.F. of the local oscillator. Then the amplitude

of the combined signal will vary periodically from (e_1+e_2) to (e_1-e_2). The received current from the local oscillator is represented by AP. This current is constant and produces no sound in the phone. With the two E.M.F.'s combined the received current varies periodically from that represented by C_2N to that represented by C_1M. This periodic variation is seen to be proportional to e_2 and not to the square of the signal strength, since NM is nearly straight. Since NM will be steeper the greater e_1 is, the signal is proportional to e_1, the local E.M.F. Thus the signal is proportional to e_1e_2.

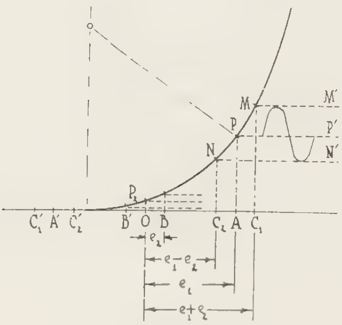


FIGURE 11.

The intensity of the signal is proportional to the product of the signal intensity and the intensity of the local oscillator. Signals which are too weak to actuate the detector can with the help of the local oscillator be detected. The signal intensity in the heterodyne method is proportional to e, the signal intensity, instead of to e^2, as in the ordinary detector. This is an advantage where weak signals are being used. Assume e to be the intensity of the signal which gives fair response. Then the response due to a signal of one-half that intensity gives a response of one-half instead of one-fourth, as in the case of ordinary detectors. A signal whose intensity is one-tenth, perhaps, could be read with difficulty, while a response of one-hundredth would be impossible to receive.

The heterodyne method of reception of continuous waves is extremely efficient. The long distance records of from 10 to $12\frac{1}{2}$ thousand miles (the circumference of the earth is 25,000 miles) with a fraction of a watt input at the transmission station, is due largely to the efficiency of the receiver at the receiving station.

173. Receiving from Arc Stations. In the arc stations it was found that it was not feasible to interrupt the flow of energy. If the arc stopped oscillating it took an appreciable time for it to start again. The arc could not follow the speed of the interruptions necessary in code transmissions. Instead of breaking and closing

the circuit a detuning method is used. The inductance in the oscillating aerial circuit is slightly changed and thus the frequency of the oscillation is changed slightly. When the key is closed one turn of the coil is shorted. When using the heterodyne method of receiving, the pitch of the beat note heard from an arc station is different when the key at the transmitter is making contact than when the key is open. By listening to the change of pitch of the tone received, the receiving operator can read the signals. It is possible to set the local oscillator to the same frequency as that of the sending station with the key open. This gives zero beat frequency and no sound is heard. When the key is closed the beat frequency changes to a rather low audible note. Thus the dots and dashes are heard the same as in regular C.W. transmission. The pitch heard is low and most operators prefer to listen to the change of pitch. The pitch is controlled by the local receiving operator.

174. Illustration of Heterodyning. Often on a small lake where there are small outboard motors, when listening to the hum of a distant motor one may hear a rising and falling of the intensity of the sound when no other boat is heard on the lake. Perhaps careful listening will reveal the sound of another boat on the far side of the lake. This second boat is not heard by itself, but it is detected by the beat note in the hum of the nearer boat.

175. Detection with Regenerative and Oscillating Circuits. In Figure 9 for the reception by the heterodyne method we have an oscillating or regenerative circuit. We will see later that the only difference between regeneration and oscillation is the closeness of coupling. In a regenerative circuit we have a feed back coil which feeds some of the energy from the plate to the grid circuit. When the coupling is rather loose, energy is fed back and the signal is amplified. Regeneration can be classed as a method of amplification. In a regenerative circuit the tube can be used as a detector, either with plate rectification or grid rectification.

176. Detection of Damped Waves with an Oscillating Tube. The coupling on a regenerative circuit can be made so the tube oscillates. It has been shown that the sensitivity of the heterodyne method is much greater than other methods. Since this is in reality a heterodyne method it is a very sensitive method, but the tone quality is very poor. Since damped waves and modulated

waves are essentially the same, it can be used for damped waves and radio telephone. The records made with single tube circuits depend upon the fact that the tube was oscillating while recieving. The call letters of the station can be made out and perhaps the tune played may be recognized but the quality of the music is very poor. With damped waves this method is very sensitive, but the signal has poor tone. The signal sounds much like escaping steam.

177. Relative Efficiencies of Methods. It is very hard to give exact figures on the relative efficiency. Much depends on the adjustments and the intensity of the signal. With damped waves from a simple wave meter actuated by a buzzer, the figures are about as follows:

Crystal detector	1
Tube, plate current rectification	2 to 6
Tube, grid condenser	10
Tube, regenerative, grid condenser	100
Tube, oscillating, grid condenser	1000

The readings were made by shunting the telephone so the signals were just audible. (Experiment 48 "Experimental Radio.")

178. Power Detectors. During the past year or so the tendency has been to increase the radio frequency amplification and not use so many stages of audio amplification. If the theoretical amplification of the screen grid tube is realized the amplification will be so great the detector will usually be overloaded. If the potential on the grid of the ordinary detector is increased until it is in the neighborhood of one volt the detector tube is overloaded and the signals will be distorted. Distortion is due to the fact that the signal "slides" off the curved portion of the grid characteristic. A less sensitive detector is needed, one which is not so sensitive for weak signals but which will handle signals of greater intensity.

One method is to use plate current rectification. This method is not so sensitive but the grid potential can be larger and still get better rectification as far as quality is concerned. If the mutual characteristic were a straight line striking the X axis, grid potential axis, at zero say, then the intensity of the rectified current will be in this case the upper half of the received signal. This

method has been applied in some sets such as R.C.A. 64. where a 227 tube is used as a detector. In this set an automatic volume control is used which keeps the signal constant within certain limits. It is proposed to use larger tubes such as a 210 power tube. In this manner the potential on the grid can be amplified to larger values.

FIGURE 12. The 227 five prong A.C. tube which can be used as a detector.

Another method proposed is to use a tube with a grid condenser and grid leak resistance but with higher plate voltage. The argument being that with low B battery the point of action on the mutual characteristic is on the lower curve. This curved portion tends to counteract the action of the curved portion of the grid characteristic. This will be especially true with strong signals since the tendency is to give the grid condenser a negative charge and to slide the point of action towards the left. In power detection using this method a small grid condenser is used and a rather low grid leak. The lower the resistance the better if it were not for the fact that the signal intensity is cut by a low resistance. The value of the grid leak is about .0001 Mf. and the grid leak $\frac{1}{4}$ to $\frac{1}{2}$ megohm.

The following table will give power output and the maximum grid voltages for various tubes. Power tubes with low amplification constant are not suited to this method.

POWER DETECTORS. (Terman.)

SMALL GRID CONDENSER, .0001 TO .000125 MF. GRID RESISTANCE 250,000 OHMS.

Tube	*Plate voltage*	*Max. volts on grid*	*Max. power output Milliwatts*
201A	135	2	15
112A	135	3	30
226	135	2	40
227	135	2	
210	250	18	100

With a large power tube the output of the detector may be great enough to work a loud speaker without any audio amplification.

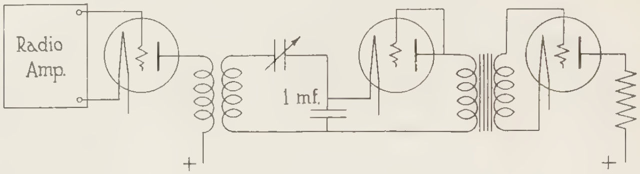


FIGURE 13.

Another proposed method of detecting is to use a two electrode tube as a detector. Figure 13 is a connection using a three electrode tube as a two electrode tube. The grid and plate are connected together.

CHAPTER XIII

THE TUBE AS AN AMPLIFIER

179. Introduction. In previous sections we have spoken of the amplification constant of a tube. The amplification constant, μ, was defined as the ratio of the change of the plate voltage to the change of the grid voltage.

In all amplifiers we use tubes, but the tubes must be connected together by some device so the amplification obtained depends on the coupling device, resistance, transformer, etc. Or the amplification obtained depends upon the "load." The load may be a resistance, as in a resistance amplifier, or it may be an impedance, as in a transformer coupled amplifier. If in the tube circuit, Figure 1 we have a resistance, R, in the plate circuit of a tube whose resistance is R_p. Then treating the circuit as a simple circuit in which a battery whose E.M.F. is μE_g and of resistance R_p, connected to an external resistance, R, the potential across the resistance, R, is $Pd=IR$ and $I=\mu E_g/(R+R_p)$. Then the potential across the resistance is $\mu E_g R/(R+R_p)$.

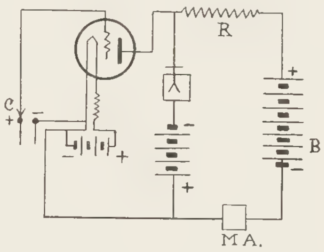


FIGURE 1.

180. Derivation from Equation. In the tube circuit diagrammed in Figure 1 we have a resistance in the plate circuit. Then the change of the plate potential is equal to the resistance times the change of the plate current. An increase of the plate current causes a diminution of the plate potential, or $dE_p=-RdI_p$. Since the current is given by

$$I_p=A+B(E_p+\mu E_g)$$

$$dE_p=-R(BdE_p+\mu BdE_g)$$

$$dE_p(1+RB)=\mu RBdE_g$$

$$dE_p=-dE_gR\mu B/(1+RB)$$

FIGURE 2. 10 Kw Amplifier. Western Electric 220B. This tube uses 10,000 volts on the plate.

since $B=1/R_p$

$$dE_p=\frac{dE_g R\mu}{R_p+R}.$$

If the term RB in the denominator is large compared to unity, then $dE_p=\mu dE_g$. B is the conductivity of the tube, Chapter XII. If R_p is equal to the resistance of the tube, then RB is unity and can not be neglected. In the case R is equal to the resistance of the tube, then $dE_p=\mu dE_g/2$.

The amplification of the circuit is one-half of that of the tube. If R is twice the resistance of the tube,

$$dE_p=\tfrac{2}{3}dE_g.$$

In general, the amplification of the circuit is $(n/(n+1))\mu$ when the resistance $R=(nR_p)$ where R_p is the resistance of the tube.

The coupling coefficient of a resistance coupling is always less than unity and approaches unity as the resistance, R, approaches infinity. The resistance, R, can not be made indefinitely large, since the average potential on the plate of the tube is $(R_p/(R_p+R)$ of the B battery potential.

If the resistance, $R=R_p$, the B potential must be 80 volts if the potential on the plate is 40 volts. If R is four times the resistance of the tube, the B battery potential must be 200 volts in order to have 40 on the plate.

The voltage amplification can be measured by placing an electrostatic voltmeter across the plate to the filament and noting the change of potential when the potential of the grid is changed a small amount. Instead of an electrostatic voltmeter a sensitive electroscope can be used, Figure 1. The electroscope must be calibrated so the change of potential can be read. As a general thing an electroscope is not very sensitive at low potentials—40 volts, say. In this case an extra B battery can be inserted between the electroscope and the filament so as to make the potential across the electroscope 100 volts or more.

181. D.C. Amplifier. In this connection it is instructive to consider a "D.C." amplifier. Suppose we connect three tubes in series in order to amplify a small steady D.C. potential. The plate of the first tube, Figure 3, cannot be connected directly to the grid of the next, since the potential of the plate is perhaps 40 volts positive. A large C battery, 35 to 40 volts, must be inserted so as to reduce this large potential to near zero; that is, to the proper potential as indicated by the characteristic of the tube.

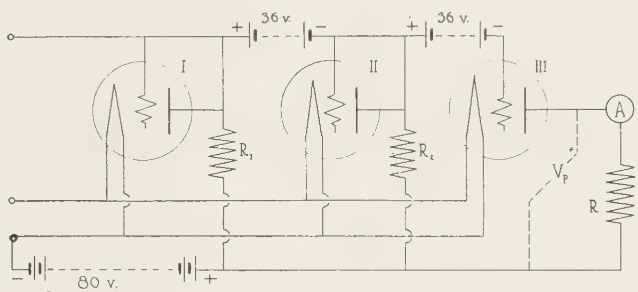


FIGURE 3.

Let us consider the action of this amplifier. Suppose the grid potential of the first tube is increased by a positive potential of 1/10 volt. The current through the resistance in the plate circuit of the tube, No. 1, is increased and the potential of the plate falls an amount equal to R_1dI_p. This causes the grid potential of Tube No. 2 to fall, and the plate of the second tube rises an amount R_2dI_2 which is communicated to the grid of the third tube. This change of grid potential causes the current in the third plate circuit to increase and the plate potential falls. The fall can be measured by an electrostatic voltmeter across the plate of the third tube, or a milliammeter in the plate circuit can be taken as an indicator, the change of current being proportional to the change of grid potential of the first tube.

If all the tubes are alike and all the resistances are equal to the tube resistance, then $dE_{p_3} = \frac{1}{2}\mu \times \frac{1}{2}\mu \times \frac{1}{2}\mu = 1/8\mu^3$, when μ is the amplification constant of the tube.

If $\mu = 7$, then the amplification is $1/8(7)^3 = 45$. If R's are 4 times R_p and the batteries be increased accordingly, the amplification $= (4/5)(\mu)^3 = 170$.

182. Impedance Load; Voltage Amplification. In the simple case with a resistance load we see that an amplification of $\mu R/(R_p+R)$ is obtained.

If the load is a coil of resistance, R and an inductance, L, the current in the plate will be $I_p=\mu E_g/\sqrt{(R+R)^2+(\omega L)^2}$. If Z is the impedance of the coil $Z=\sqrt{R^2+(\omega L)^2}$, the voltage amplification is then $\mu Z/\sqrt{(R_p+R)^2+(\omega L)^2}$.

If the coil has little resistance, then the voltage amplification is $\mu\omega L/\sqrt{R_p^2+(\omega L)^2}$.

In general, the voltage amplification is $\mu Z/(R_p+Z)<ZR_p$, where the term $<ZR_p$ means Z and R_p are to be added vectorally.

If the coil has large inductance and little resistance, the voltage amplification is nearly equal to μ. Since the resistance of the coils is small, the potential on the plate is equal to the potential of the B battery. The phase angle $\phi=\tan^{-1} Z/(R_p+R)=\tan^{-1} L\omega/R_p$ when the coil has little resistance.

Amplifiers are usually amplifiers of alternating current and the equations written in the form $dI_p=\mu dE_g/(R_p+Z)<ZR$ perhaps is the better form, since dI, change of current, is interpreted as meaning A.C. current and dE, change of E.M.F., as A.C., E.M.F. Here the resistance, R_p, is the resistance of the tube which is the reciprocal of the slope of the plate characteristic curve and varies from point to point unless the curve is a straight line. These curves usually are not straight but as a usual thing the theory is developed assuming them to be straight, and remembering that R_p is an average value of the tube resistance. If we write the equations using the differential form the value of the voltage amplification comes out to be the same as the values derived above.

183. Current Amplification. In Section 12 we have said that a current amplification constant is, as a general thing, an ambiguous quantity. We perhaps might give it a definite meaning if we restrict it in a certain manner. If we assume that our input current must flow through an input resistance, then we can apply the Pd across the resistance to the grid of the tube and measure the current, or rather change of current, in the plate circuit. If we call the input current dI_1 then $dE_g=R_1dI_1$, Figure 4, then we have the output current

$$dI_p=\mu R_1dI_1/(R_p+R).$$

The current amplification constant, $\eta = dI_p/dI_1 = \mu R_1/(R+R_p)$. To make this intelligible we must have a resistance in multiple with the grid and a load resistance in series with the plate.

Our D.C. amplifier, Figure 3 could be made to amplify current if the current flows through a resistance, R_1 and the first tube is connected around this and a milliammeter is placed in the plate circuit of the last tube. The current, I_1, will be amplified into a value as shown by the change of current of the milliammeter. The grid bias of the last tube might be adjusted so the milliammeter reads zero when I_1 is zero, but under this condition the last tube will be working on the curved portion of the characteristic curve and the amplification will not be constant. It must be remembered that if the current, I_1, is taken to be the current flowing into the grid of the first tube, the expression becomes meaningless, since this grid current is vanishingly small. In this case it is suggested that, instead of an amplification constant, the condition be given in terms of A_{cv} or current output per volt input. Since the voltage amplification $A_v = \mu R/(R_p+R)$, then since amperes$=E/R$, $A_{cv} = \mu/(R_p+R)$.

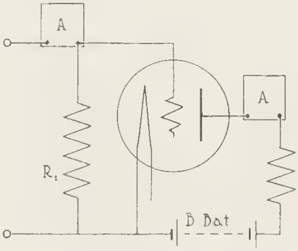


FIGURE 4.

184. Power Amplification. Like current amplification, it is hard to measure the grid input of a tube, so it is better to express the power output in terms of the potential on the grid.

Since power is equal to E^2/R, we have

$$A_{pv^2} = (\mu R/(R_p+R)^2/R = \mu R^2/(R_p+R)^2.$$

A_{pv^2} is read, power output per volts squared input.

In most amplifiers all stages except the last stage are designed for voltage amplification. The last stage is usually designed for power amplification. The power output is proportional to the square of the input voltage and not to the input power.

An amplifier is usually not designed to give the maximum amplification possible. It is designed to give undistorted amplification. Beyond this limit the amplifier should not be used. This involves the discussion of amplification with respect to the characteristic curves. The subject will be taken up again under amplifiers.

185. Regenerative Amplification. In some circuits, in fact, in most circuits using short waves, some of the energy from the plate circuit is fed back into the grid circuit. As long as the amount is less than a critical amount, the amplification is much increased. There are a large number of these circuits. One of the most simple is the "tickler" coil feed back circuit. This circuit consists of a tuned circuit in the grid circuit and a "tickler" coil in the plate circuit. The tickler coil is so placed that the changing current in the plate circuit inductively induces an E.M.F. in the grid circuit. The connection is made as in Figure 5.

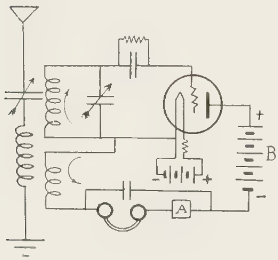


FIGURE 5.

Suppose that from an outside source, a current in an aerial, perhaps, the current at a particular instant is running in the coil in the grid circuit, clockwise toward the grid as indicated by the arrows. Since the grid potential is increasing, the plate current will increase. Then if the tickler coil is so placed that the current is flowing anti-clockwise, then the induced E.M.F. is clockwise in the grid circuit. This will increase the potential of the grid and cause the change in the plate current to be much increased.

This method of amplification of radio frequency is very efficient in a receiver. The only trouble is there is danger of the circuit amplifying too much and the set becoming a generator of high frequency current which will make a disturbance which may be detected miles away.

The above circuit is only one of many. Others will be given under Oscillators.

CHAPTER XIV

THE TUBE AS AN OSCILLATOR

186. Introduction. If we connect the tube to a wave meter circuit as in Figure 2, Chapter XII, and a positive pulse of potential is given to the grid, there is an increase of the current in the plate circuit through the telephone.

There has been an amplification due to the fact that the tube always is an amplifier. The extra energy comes from the B battery. There is no "perpetual motion" in tube circuits, in the sense that we manufacture energy. We pay in B batteries for all we get. There is amplification, the amount depending on the tube and, to some extent, on the circuit.

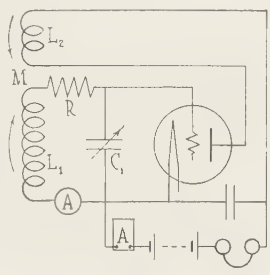


FIGURE 1.

If a coil, L_2, is placed in the plate circuit and coupled to the tuning coil, L_1, Figure 1, and if the coupling is made right, some of the energy in the plate circuit is fed back to the coil in the grid circuit. This will be recognized as being practically the same as the circuit which was called a regenerative circuit in Chapter XIII under regenerative amplification.

If the coupling is increased, there will come a time when the energy fed back is greater than the losses. The currents always are of such a value that the losses in the circuit are equal to the energy supplied to the circuit. Most or all this energy is dissipated as heat, or I^2R losses. As the energy is fed back by the tickler coil to the primary coil, the plate current increases and, of course, the I^2R losses increase.

Figure 2 is a hypothetical curve representing the relation of the losses, assumed to be all heat losses, and the energy fed back to the circuit by the tickler coil. The dotted straight line *oab* represents the curve which shows the relation if the losses were always just equal to the energy supplied to the circuit. This would be the condition for a circuit like that of Figure 2 Chapter XII, where

there is no energy fed back. All the energy is supplied by some outside source. Let the curved line *oab* represent the energy fed back to the circuit by the coil L_2. Suppose the energy is changed in some manner, a simple way is to vary the filament current. From *o* to *a* we have regeneration. Some energy is given to the circuit by an outside source, aerial, say, and some is fed back by the coil, L_2. Near *o* there is very little energy fed back, and most of the energy must come from the aerial. As the curve approaches the point *a*. the regeneration is very great, but in order to have any current we must have some little supplied by the aerial. At *a* the energy fed back is equal to the energy dissipated, and since the curve follows the dotted curve to *b*, it is in unstable equilibrium. This unstable equilibrium is different from most cases of unstable equilibrium, instead of tumbling down, the tumbling is upward. It is perhaps like two cars tied together by a rather long tow rope. Assume the first car is at the top of the hill, or perhaps over the hill and down a little on the other side. We have forgotten the first car and are concerned with the second. In order to get this up it is necessary to push. As we push it moved easier and easier until it starts of its own accord towards the top. The equilibrium became unstable and the car started up the hill. We have forgotten the first car, and we can explain the situation if we wish by saying we have negative friction and the car went up.

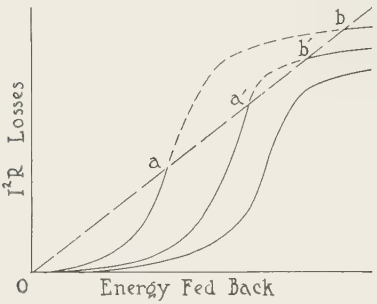


FIGURE 2.

Our circuit which we left at the point *a* of the curve, is on the unstable part and we soon find it on the point *b*, where the losses are equal to the total energy received. Practically all this energy now comes from the feed back. The aerial may be, and usually is, receiving more energy from our circuit than it is giving to the circuit. This is sometimes explained by saying that there is negative resistance in the circuit. However, the circuit is not cooling off, due to the negative I^2R losses. It will be found that the circuit is heating up. The extra energy comes from the B battery.

The energy in the case of the car came in some mysterious manner from the far side of the hill, which we did not see.

By changing some of the constants of the circuit, the coupling between L_1 and L_2, our curve may take the form of $oa'b'$. Here the circuit a oscillates but there is not much difference between the point of starting and the equilibrium point, b'. If the coupling is loosened more the circuit will not oscillate but there may be some feed back. This is illustrated by the curve which does not cut the straight line, Figure 2.

187. Oscillation Explained. If we consider the mutual characteristic curve, Figure 5, together with the circuit in Figure 1, we see that if for some reason as the potential of the grid becomes more positive the plate current, I_p, increases, and if the coil, L_2, is connected right the increasing current induces an E.M.F. in coil L_1, making the grid potential more positive. This increases the plate current and in turn this again increases the grid potential, E_g. This action keeps up until there is equilibrium and then the plate current becomes constant and the E.M.F. induced in L_1 is zero. The equilibrium position for E_g is at the point marked zero, and the grid potential changes toward the negative direction. This causes the plate current to diminish and this induces in L_1 a negative potential, which in turn diminishes the plate current until a constant value near zero is reached. At this point the grid potential is negative with respect to the zero or equilibrium value. The grid increases in potential and causes an increase of plate current, which again causes the grid to become positive and the cycle is repeated. The frequency will be the natural frequency of the circuit which is governed in the main, by the capacity C_1 and the inductance L_1.

In the plate circuit we have a pulsating current, and in the tuned grid circuit we have an alternating current of high or low frequency, one million cycles, perhaps, possibly one cycle, depending on the value of L_1 and C_1. The plate current can be thought of as consisting of a D.C. current and an A.C. current superimposed one on the other. The values of these currents are such that at no time is the sum equal to a negative current. At times the sum may be zero, but not negative.

188. The Oscillating Tube and Parallel Resonance. It is instructive and gives one an insight into the cause of the oscillation to consider the oscillating tube to be a special case of parallel reso-

nance. For this purpose we shall connect our tube in a Tuned Plate circuit, Figure 3.

In this circuit our elementary wave meter circuit is placed in the plate circuit of the tube instead of in the grid circuit, and the tickler or feed back coil is placed in the grid circuit. Thus in the plate circuit in which there is alternating current, we have a condenser, C, and an inductance, L_1, in parallel. The A.C. circuit in the plate of the tube is the vector sum, or vector difference, of the two currents in the coil and in the condenser. (See Parallel Resonance, Chapter IV, Alternating Current.)

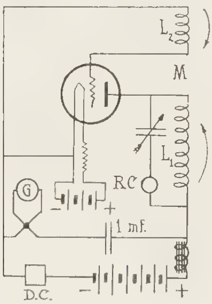


FIGURE 3.

The grid circuit can be considered to be a device which varies the plate current and which takes little or no energy. The plate current can be considered to have two components, a constant direct current and an alternating current, the frequency of which is governed by L_1 and C in the tuned circuit. The A.C. current in the plate circuit then is the resultant of the two currents, one the condenser current and the other the current through the coil. These two currents are practically the same in numerical value and almost in opposite phase.

Let the vertical dotted line represent the direction of the E.M.F. If the resistance is considered to be all in the coil the condenser current is represented by OC which has a positive phase angle of 90° in advance of the E.M.F. The current through the coil lags behind the E.M.F. by an angle whose tangent is represented by the angle VOl. The current through the coil is represented by Ol, whose magnitude is approximately equal to OC, and nearly opposite to OC. Both are equal to the current as measured by the radio ammeter in series with the condenser. The vector difference is Op and is equal to the current in the plate.

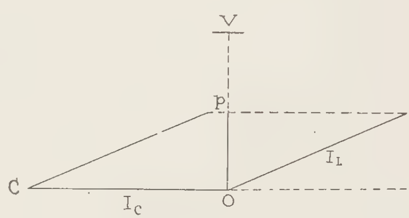


FIGURE 4.

The plate current can be read by means of a thermo-junction in series with a large condenser which is in parallel with a choke coil, or the A.C. can be estimated from the readings of the D.C. milliammeter in the plate circuit. Having the three currents given, the parallelogram *OCpl* can be laid out. Since the resistance is all assumed to be in the coil circuit, the tangent of the angle *VOl* equals $L\omega/R$. This can be checked by measuring the resistance of the circuit, CL_1, and the inductance of the coil and the frequency of the circuit.

Thus the oscillating tube is simply a D.C. circuit which contains an automatic reverse key or commutator which requires little or no energy to operate. In this circuit we have a coil and condenser for parallel resonance. The large currents measured in the tuned circuit are explained by the theory of parallel circuits. The resistance, R, measured in the resonant circuit, is made up of the resistance of the coil and condenser and the equivalent resistance of the resistance in the plate circuit, tube resistance or otherwise.

A study of this circuit in connection with the theory of parallel resonance will give one an insight into the theory of tube generators.

189. Conditions for Oscillation; Tuned Grid Circuit. The following is an elementary approximate discussion of the action in a tube circuit such as the tickler circuit of Figure 1. It is well to remember that when the circuit is oscillating that energy is supplied by the battery as fast as it is dissipated in the resistance of the circuit. In this the resistance, R, supposed to be located in the oscillatory circuit C.R. and L, is the equivalent resistance of all resistances in the circuits. If the circuit is radiating, or if energy is being absorbed by outside objects, R includes the equivalent resistance of the radiation or absorption. If the supply of energy is suddenly shut off, then the current dies down according to the law $I = I_o e^{-R/2L} \sin \omega t$, as in a damped wave circuit.

Assume an alternating current in the tuned circuit, then the alternating potential of the grid is $E_g = I/C\omega = IL\omega$. The alternating plate current, $I_p = E_g G$, where G is the mutual conductance. Then $I_p = IL\omega G$. The induced voltage in the tuned circuit due to the tickler coil is $I_p M\omega = IL\omega GM\omega = ILGM\omega^2 = E$.

The energy is $IE = I^2LGM\omega^2$. When this is less than I^2R the circuit is regenerative but will not oscillate. The condition for oscillation is

$$I^2R = I^2LGM\omega^2, \quad \text{or} \quad R = LGM\omega^2,$$

since $\omega^2 = 1/LC$, $R = GM/C$.

When $LGM\omega^2$ is greater than R, the tube begins to oscillate and the current, I, in the oscillating circuit, R, L, C, becomes much greater. This increases until there is equilibrium. I_p, the current in the plate circuit, makes excursions up and down the characteristic curve, Figure 5, from the lower bend at zero up to the upper bend. The D.C. component is near the middle of the characteristic. As a general thing, the D.C. milliammeter in the plate circuit will increase from I_{po} to I_p when the tube begins to oscillate.

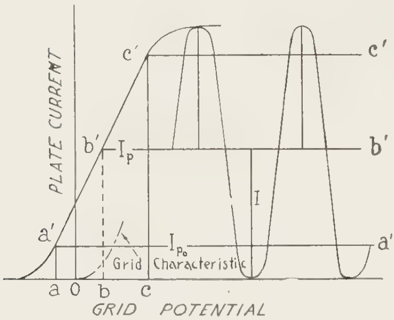


FIGURE 5.

190. Condition for Oscillation; Tuned Plate Circuit. A somewhat more rigorous explanation of what happens in the tube circuit is given by the solution of the following differential equations. The equations will be set up and the final form of the solution will be given here.

In this case, assume we have a tuned circuit in the plate circuit, as in Figure 3. This circuit is sometimes called the reverse feed back circuit. In the plate circuit we have a circuit which in alternating current is known as a parallel resonant circuit. (See Alternating Current, Chapter IV.) In the tuned plate circuit, if the resistance is not very large the current in the condenser is nearly at right angles with the E.M.F. in the positive direction and the current through the coil lags almost 90°. The resulting current is the vector sum of these currents and is relatively very small.

If I_C, I_L, I_p, are the currents through the condenser, coil and plate respectively, the vector sum of the two is equal to the plate current, $I_p = I_C - I_L = GE_g - BE_p$. Remember that the mutual conductance, $G = \mu/R$ and the conductance $B = 1/R_p$.

$$E_g = MdI_L/dt, \qquad E_p = -RI_L - LdI_L/dt$$

$$I_C = -CdE_p/dt = CRdI_L/dt - CLd^2I_L/dt^2.$$

Substituting in the equations for the currents, and writing I for I_L we have,

$$CRdI/dt-CLd^2I/dt^2-I=GMdI/dt-BRI-BLdI/dt,$$

or

$$CLd^2I/dt^2-(CR-BL-GM)dI/dt-(1-BR)I=0.$$

The solution of this equation can be put into the form

$$I=I_0e^{\alpha t}\sin\omega t,$$

when

$$(CR+BL-GM)<4CL(1+BR),$$

where

$$\alpha=-\frac{CR-BL-GM}{2CL}$$

and

$$\omega=\sqrt{\frac{1+BR}{CL}-\frac{(CR+BL-GM)^2}{4C^2M^2}}.$$

If α is positive, the circuit will build up and oscillate. If α is negative the oscillation will decrease, or the circuit will not oscillate. $\alpha=0$, is the condition for starting the oscillation and remaining constant. It is understood that in the final state of oscillation, $\alpha=0$.

When the circuit is oscillating

$$\omega=\sqrt{\frac{1+BR}{CL}-\frac{(CR+BL-GM^2)}{4C^2L^2}}=\sqrt{\frac{1+BR}{CL}}=\sqrt{\frac{1}{CL}}.$$

If BR is small compared to unity, as is usually the case, the frequency of the circuit is the natural frequency of the circuit, C, L. This is approximately true if the wave length is long. For short waves there is in general an appreciable difference.

The resistance as measured by the half deflection method will be a few ohms—usually under 20. In this case, 20 times B, the conductance, or 20 divided by the plate resistance can be neglected.

191. Indications of the Oscillations. The oscillating current can be detected by placing a thermalammeter in series with the condenser of the tuned circuit, provided the current is several milliamperes. Often the power delivered is not enough to show on the thermalmeter, or it is inconvenient to use a thermalmeter. A D.C. meter in the plate circuit, or even a telephone, can be used to tell when the circuit is oscillating.

In order to understand the action of the meter in the plate circuit, consider the diagram, Figure 5. The curve represents a mutual characteristic and the sinusoidal curve represents the fluctuations of the plate current in an oscillating circuit. If this curve is a true sine curve the D.C. meter will read the average current, which will be in the middle at $b'b'$. If the grid potential, E_g, is at the point a, the plate current will be represented by the line $a'a'$. When the tube begins to oscillate, the plate current rises to a value near $b'b'$. If the grid potential is changed to the value represented by c by means of a C battery, the current is $c'c'$ when not oscillating but when oscillation starts the current falls to the average value near $b'b'$. If the grid potential is such as to make the plate current read on the middle point of the curve at b, there will be no change of the plate current when oscillation starts.

Thus a plate ammeter in general suddenly changes its reading when oscillation starts. This makes a good oscillation indicator. A telephone in the plate circuit gives a peculiar click or flop when the current changes. If one stops and starts the oscillations of a small tube by touching the grid of the tube, this click is heard and one can be sure the circuit is oscillating.

192. Bypass Condenser; Blocking Condenser. If in the plate circuit a telephone, meter or other instrument with high impedance is placed, it will be necessary to have a condenser placed around the impedance to bypass the radio current. The impedance of the condenser for high frequency current is much less than the resistance of the phones. It is well to place this bypass condenser around the B battery as in Figure 3. When placed around the battery, the condenser must be insulated high enough to stand the potential of the battery. For radio frequency a condenser whose capacity is .001 M.F. or larger, will work. The impedance of an .001 M.F. condenser at 1000 Kc is near 150 ohms. This condenser is sometimes called a blocking condenser, since it blocks or stops the direct current from flowing.

193. Oscillation Characteristic of a Tube. If a tube is connected as in Figure 6 so that the grid potential can be changed to values either plus or minus and the readings of the D.C. meter are taken and plotted against the grid potential, as in Figure 7, a curve like the heavy line marked "oscillating" is obtained. This curve is the oscillating characteristic of the tube. If the feed back coil is shorted by the key, K, and the readings are taken and plotted, the dotted curve is obtained. This will be seen to be the regular mutual characteristic of the tube.

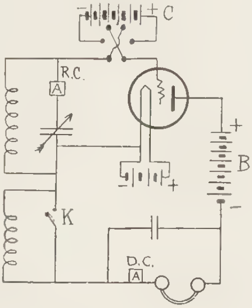


FIGURE 6.

A full understanding of this curve in connection with the curves in Figure 5 will be a great aid in understanding the action of the oscillating tube.

194. Efficiency of a Tube Generator. In Figure 5 when the tube is oscillating, the D.C. component of the plate is represented by the line $b'b'$ and if the alternating current is represented by a sine curve which extends from the zero line to a line marking the top of the mutual characteristic, then $b'b'$ represents the amplitude or maximum value of the alternating current. Then virtual current is $I_{max}/\sqrt{2}$. So if the maximum value is divided by 1.41 we have the A.C. current generated. The current measured by a thermal meter in the tuned circuit is much larger, but one must remember the A.C. component of the current is the component which is in phase with the A.C. E.M.F. in the plate circuit. See the diagram, Figure 4. The power in the plate circuit is $I^2R = I^2_{max}R/2$. The D.C. energy delivered by the B battery is I^2R. Since the direct current is the same as I_{max}, the output is one-half of the input and the efficiency is 50%. The output as thus measured in the plate circuit can be transferred to the oscillating circuit. Here the power is I^2R where the current is the

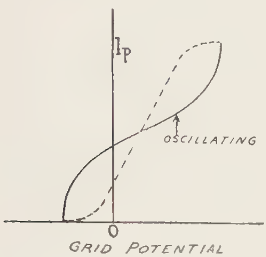


FIGURE 7.

current measured by the thermal meter and R is the resistance of the oscillating circuit as measured by the resistance variation method or any other method. The resistance in the plate circuit will be transformed into an equivalent resistance which will appear as resistance in the oscillating circuit. This is much like finding the equivalent primary resistance of a resistance which is in the secondary circuit of a transformer.

Practical measurements of efficiency are made by measuring the I^2R energy in the oscillating circuit. The output and the input is IE where I is the D.C. meter reading and E is the B battery E.M.F.

195. Oscillating Circuits. So far, we have used two circuits, the tuned grid circuit or feed back circuit, and the tuned plate or the reversed feed back circuit. These circuits have been diagrammed in Figures 1 and 3. If in the tuned grid circuit we disconnect the tickler coil L_2 from the position next the plate of the tube and place it between the filament and the negative end of the B battery, we have a circuit as diagrammed in Figure 6, the key, K, open, or Figure 8, I.

When the coil is turned in the right direction to get the tube to act as a generator, the windings will be such that the two coils could have been parts of a single coil with the filament connected to a tap near the middle. This circuit is shown in Figure 8, II. In this the coupling can not be changed except by changing the filament tap on the coil. This will change the inductance in L_1 and of course the wave length changes.

The condenser can be moved so as to include both coils as in Figure 8, III. This becomes a Hartley circuit, a Hartley series. In this the wave length is determined by the two coils in series or simply as one coil and the condenser C_1. Changing the filament tap does not change the wave length.

In the Hartley series we have placed a bypass condenser around the phone and battery. Since the A.C. current passes through the condenser and the coil, and D.C. current has no inductive effect in the coil, the negative of the B battery can be connected to the filament and we have the Hartley shunt circuit, Figure 8, IV. The Hartley shunt requires a telephone or an inductance in the plate circuit to force the R.C. through the condenser.

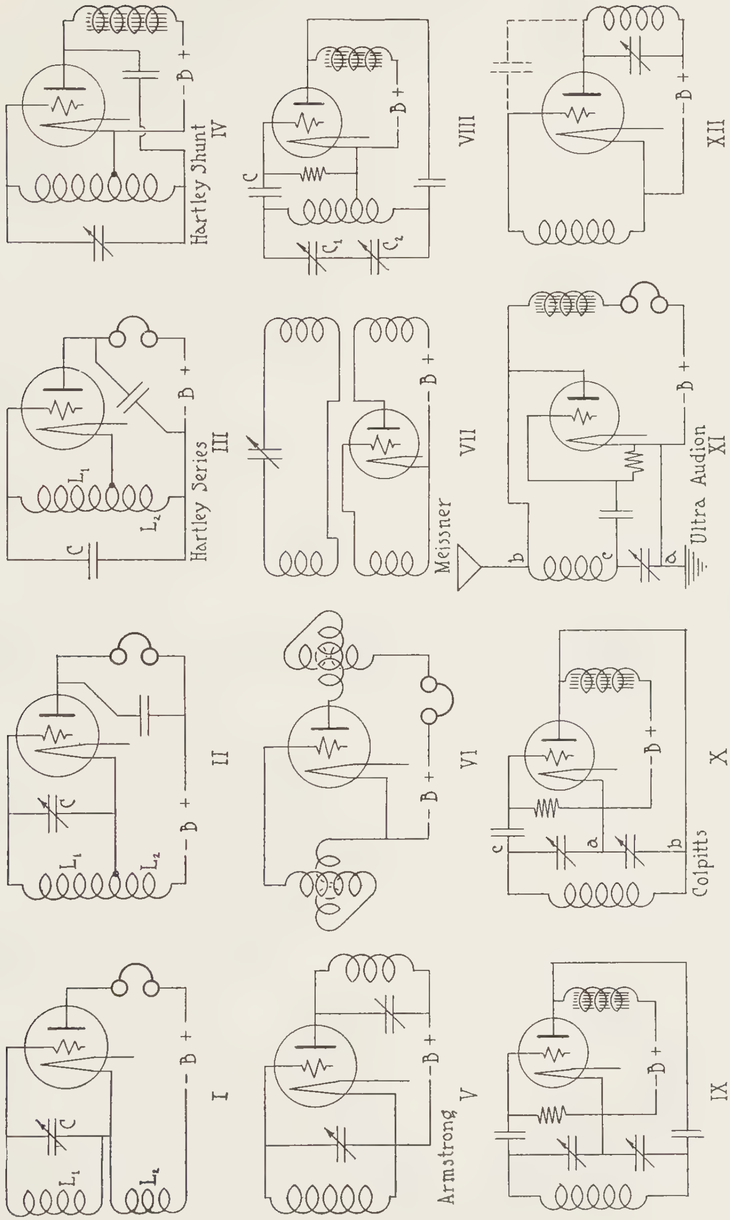

I
II
Hartley Series
III
Hartley Shunt
IV
Armstrong
V
VI
Meissner
VII
VIII
IX
Colpitts
X
Ultra Audion
XI
XII
B +
L_1
L_2
C
C_1
C_2
a
b
c

FIGURE 8.

If in the tickler coil circuit, (Figure 1), the tickler coil is placed as in Figure 8, V, the circuit will not oscillate until a condenser is placed across the tickler coil and tuned to the same frequency as the grid circuit is tuned. This circuit is known by several names, Armstrong, grid and wing, etc. Some years ago this circuit was very popular. The necessary circuit tuning was done by two variable inductances or variometers, one each in the grid and plate circuits. Figure 8, VI is such a circuit. If the condensers are removed from the circuit 8, V the tube will not oscillate, but if they are coupled inductively by another tuned circuit the tube will oscillate. This is known as the Meissner circuit. Figure 8, VII.

Figure 8, VIII is a Hartley shunt circuit in which the condenser has been replaced by two condensers in series. A grid condenser with grid leak has been added. These have the effect of a C battery. The effect is to make the grid more negative. The filament is connected to a tap on the coil near the middle of the coil. If we choose to call the potential of the filament zero, there is some point in the condenser which has zero potential. We shall assume that this point is the junction between the condensers.

In Figure 8, IX, we have the connection of filament to the mid point between the condensers. This is the Colpitts circuit. Since we have a grid condenser in the circuit we can discard the bypass condenser and we have the circuit of Figure 8, X, which is the true Colpitts circuit.

In the last Colpitts circuit, Figure 8, X, the connections are lettered *a*, *b*, and *c*. If one of the condensers is an aerial, the ground being connected to the filament connection, we have the Ultra Audion receiving circuit. Figure 8, XI.

It is possible to make gradual transformations from one circuit to another until all the many circuits have been diagrammed. A circuit may look like a new circuit, but after it has been unscrambled it may be seen to be one of the fundamental circuits. Some of these are fundamentally magnetically inductive feed back circuits. Others, such as the tuned plate and tuned grid circuits, are fundamentally electrical inductive feed back circuits.

196. Capacity Feed Back. In Chapter XIII we saw that when there was a resistance in the plate circuit the potential of the plate fell as the plate current increased, and rose when the plate current decreased. If instead of a resistance in the plate circuit we have a

tuned circuit, as in Figure 8, XII, the plate current is in phase with the E.M.F., and the tuned circuit acts as a large impedance in the plate circuit. Since the tube is a condenser, there is capacity of measurable values between the plate and grid. Think of the tube as a condenser or as an imaginary condenser shunted across the plate and grid. When the potential of the plate increases, condenser current runs into the plate side of the condenser and the same amount of current runs out of the grid side of the condenser. Since current has run out of the grid side of the condenser the potential of the grid has diminished. The plate side being positive induces negative on the grid side. This makes the grid more negative than it otherwise would be. This tends to stop the plate current from flowing and thus the plate potential rises or becomes more positive. This drives the plate current toward zero. When the plate current begins to increase, the grid is made more positive, and the current increases up to higher values. Thus there is regeneration through the capacity of the tube. The circuit is then an electrically inductive feed back, or simply a capacity feed back.

FIGURE 9. A R.C.A. 1 kw tube which can be used as an oscillator.

In short waves this capacity feed back is very great and there is trouble in keeping the tube from oscillating.

In most circuits magnetic and electric feed back operate more or less. Some are primarily magnetic, or inductive, others primarily electric or capacity feed back.

197. The Screen Grid Tube. It is hard to know just where to place the discussion of the screen grid tube. The screen grid tube as it is now known is a four element tube. It has two grids. The filament, ordinary or control grid, and the plate are practically the same as in the three electrode tube. The second grid is constructed so it practically surrounds the plate on all sides, inside and outside.

Figure 10 shows the construction of the R.C.A. 222 screen grid tube. It also shows a screen placed over the tube.

The tube as usually used is used as a screen grid tube in that the screen grid is used as a constant potential screen around the plate

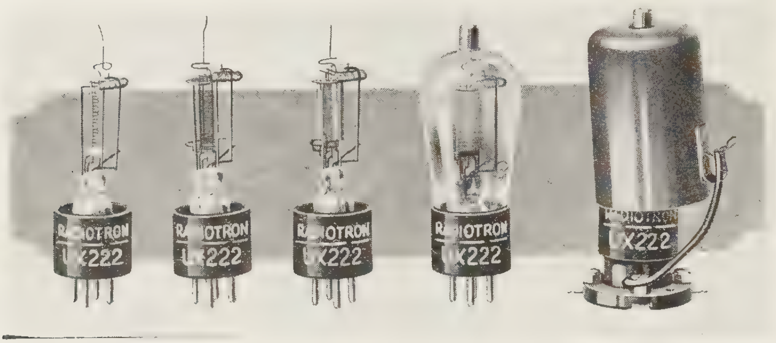


FIGURE 10.

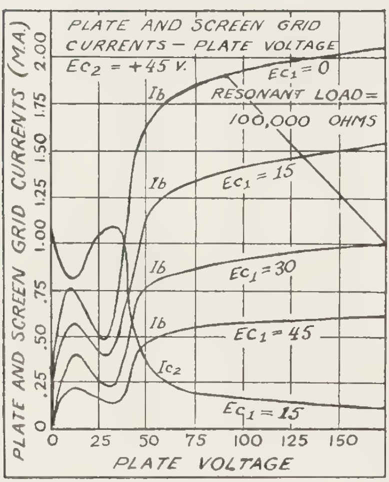


FIGURE 11.

and effectively does away with the capacity between the grid and the plate and prevents oscillation due to tube capacity.

The screen grid has an amplification constant of about 300, and like other high mu tubes it has a high plate resistance in the order of megohms. Using the control grid to steady the regenerative action it is possible to use this tube as an amplifier and get a rather large amount of amplification per stage. With radio frequency amplification an amplification of twenty five per stage can be realized. With this high amplification any feed back in the circuits will cause the tube to oscillate so it is necessary to screen the circuits as well as the tube.

Figure 11 is a set of plate characteristic curves of the 222 screen

grid tube. Figure 12 is a circuit using a screen grid tube as an oscillator.

Figure 10 Chapter XXV is a diagram in which the screen grid tube is used as a radio frequency amplifier.

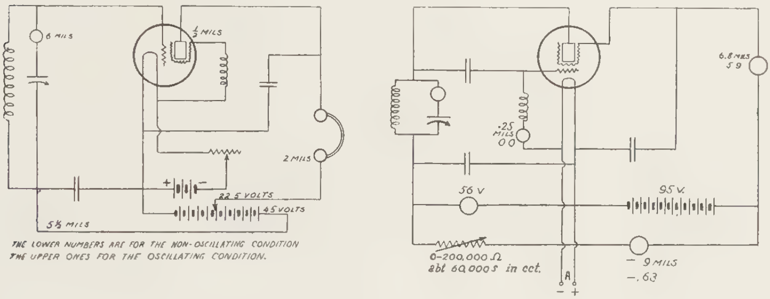


FIGURE 12.

A number of power screen grid tubes have been made for transmitting use. Figure 21 Chapter XXIII is a circuit in which a screen grid power tube is a transmitter tube.

198. Low Frequency Oscillator. If an iron core transformer such as an audio transformer is connected as in Figure 13 an oscillator ay audio frequency can be made. If the connection of Figure 13 is changed into a Hartler circuit, Figure 8, III, by placing the condenset around the two coils instead of around one, the frequency can be made lower. If the inductance of the transformer is large and a large condenser is used, the frequency can be made low enough so that the oscillations can be counted.

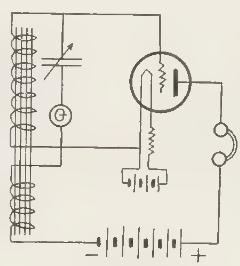


FIGURE 13.

In connecting the audio transformer, connect the condenser around the secondary and use the primary as the feed back. There is no rule as to the terminals of the transformer. The proper connection must be determined by trial.

A galvanometer placed in series with the condenser will have pure alternating current through it and will respond to the individual vibrations if they are not too fast.

CHAPTER XV

COUPLED CIRCUITS

199. Introduction. In radio circuits we usually have more than one circuit to deal with. These circuits are coupled together in various ways, and their constants and mode of responding to the E.M.F. depend upon the manner of coupling. There are three general methods of coupling—conductive coupling, inductive coupling, and capacitative coupling. There may be and often are combinations and variations of these three kinds of coupling.

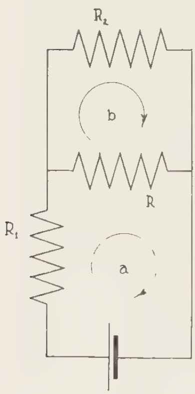


FIGURE 1.

200. Conductive Coupling. Figure 1 which is an ordinary shunted circuit containing resistances and a battery, is a case of conductive coupled circuit. The two circuits *a* and *b* are coupled together by the resistance, *R*. Circuit *a* consists of the battery, the resistance, R_1, and the coupling resistance, *R*. Circuit *b* consists of the coupling resistance, *R*, and the resistance R_2. A circuit can be worked out by applying Kirchhoff's laws or by the ordinary law of shunts as applied in elementary texts. It will be noted that if we apply Kirchhoff's laws we must consider the currents of both circuits to be running through the coupling resistance, *R*, in opposite directions.

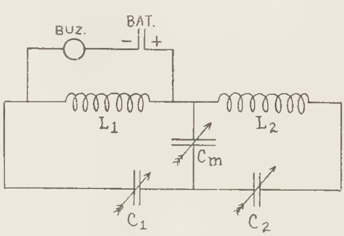


FIGURE 2.

201. Capacitive Coupling. Figure 2 is a case of two circuits which are capacitatively coupled. The coupling condenser, C_m, belongs to both circuits. In this circuit the E.M.F. applied to the circuit, 1, is due to the buzzer and battery. This will be seen to be a damped E.M.F.

202. Inductive Coupling. The circuit, Figure 3, is that of a tube generator connected to the circuit, C_1, L_1L, so as to make a Hartley series circuit. The circuit, L, L_2, C_2, is connected to the first by the coil, L. This circuit can be said to be self-inductively coupled. Since the coil has resistance as well as inductance, the coupling is a combination, resistance and inductance coupling.

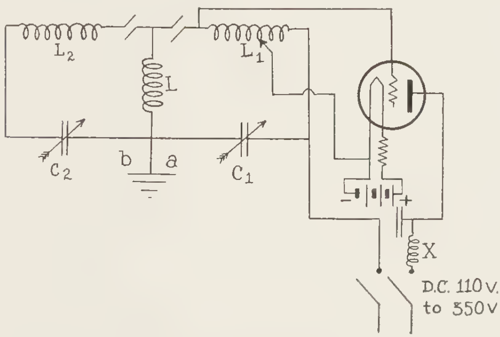


FIGURE 3.

Figure 4 is a case of transformer coupling. Circuits *a* and *b* are coupled together by the mutual inductance between the coils of circuits *a* and *b*. As placed in the figure, *a* and *b* are close coupled, while the wavemeter is loose coupled to the other circuits. In the wavemeter circuit the phones and crystal circuit is capacitatively coupled to the wavemeter.

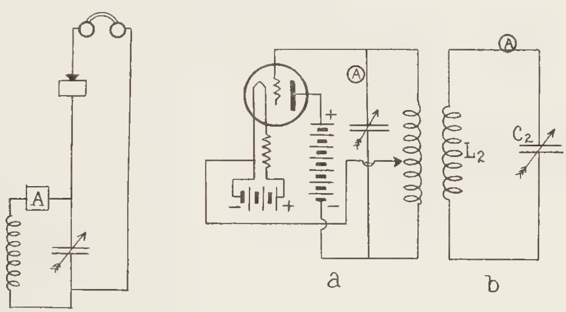


FIGURE 4.

Figure 5, are two circuits with involved coupling containing resistance, self-inductance, capacity and mutual inductance.

203. Equivalence of Coil and Transformer Coupling. In Figure 6 we have two circuits which are equivalent if the coil, L, in the first circuit has no resistance, and if its inductance, L, is equal to the self inductances, and mutual inductance of the transformer

in the second circuit, or if $L = L_m' = L_m'' = M$. Then under these circumstances we see that if we remove the second circuits from

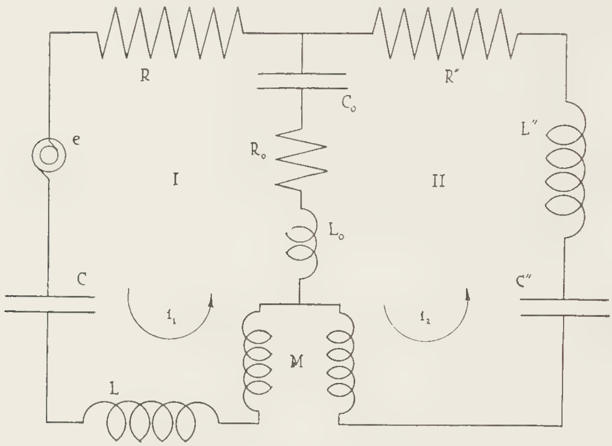


FIGURE 5.

both diagrams the first circuits are identical and likewise the second circuits are identical if the first circuits are removed.

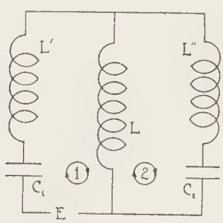


FIGURE 6a.

$L_1 = L' + L$

$L_2 = L'' + L$

Coupling, $m = L$.

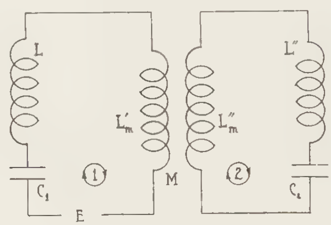


FIGURE 6b.

$L_1 = L' + L_m'$

$L_2 = L'' + L_m''$

Coupling, $m = M$.

FIGURE 6.

204. Reactance and Susceptance Diagrams. In our equation for current with resistance, inductance and capacity we have

$$I = \frac{E}{\sqrt{R^2 + (L\omega - 1/C\omega)^2}}.$$

The reactance due to the inductance, L, increases directly as ω. The reactance of the condenser is inversely as ω. Then the reactance of the coil, which we shall consider to be positive, is represented by a straight line in Figure 7. The reactance of the condenser is considered to be negative, and is represented by an equilateral hyperbola drawn below the zero line. The resultant or actual reactance is represented by the difference of these lines which is represented by the curved line marked "total reactance." This applies to a series resonance circuit, Figure 8.

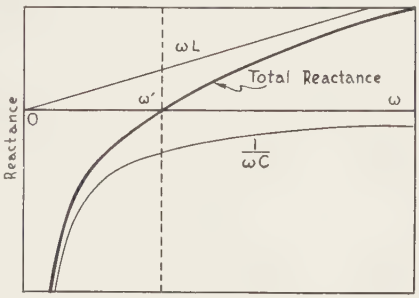


FIGURE 7.

The diagrams in Figure 7 represent the change of the reactance as ω, or the frequency is changed. The line marked total reactance crosses the zero axis at ω', which is the value at which the reactance is zero, or at which the impedance is a minimum and the current is a maximum.

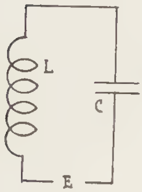


FIGURE 8.

In parallel circuits, Figure 9, the total current is equal to the sum or vector sum of the separate currents. Instead of calculating reactance it is better to calculate susceptance, which is the reciprocal of the reactance, Figure 10. Susceptance and reactance have the same relation to each other as conductance and resistance.

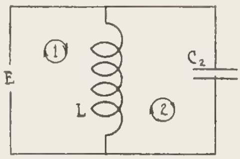


FIGURE 9.

In Figure 11, which is a simple parallel resonance circuit in series with the condenser, C_1, the susceptance of the coil is $1/L\omega$, and the susceptance of the condenser is $C_2\omega$. Plotting these in Figure 10 we have a straight broken line, ωC_2, for the condenser and a curved broken line, $1/L\omega$, for the coil. The difference is the heavy broken line passing through ω_0, at which point, the susceptance is zero, the reactance is infinite and the current is zero. If there is some resistance

in the circuit the impedance is a maximum and current is a minimum at this value of the frequency. If the reciprocal of the ordinants of the line marked "Total Susceptance" is plotted we have the full line curves marked "reactance." The reactance changes from plus infinity to negative infinity at the point ω_0.

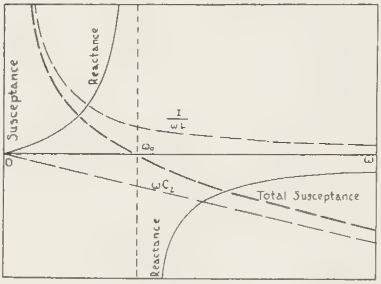


FIGURE 10.

If to the reactance, X'', of the parallel circuit we add the reactance of the condenser C_1, we have the total reactance as given in Figure 12. The circuit has a natural frequency corresponding to ω', and a frequency ω_0 where the current is a minimum. ω_0 depends on the parallel circuit. If one wishes to reject a certain frequency, a harmonic in a generator circuit or a disturbing station in a receiving circuit, a parallel resonant circuit can be placed in series with the main circuit and tuned to this frequency, ω_0.

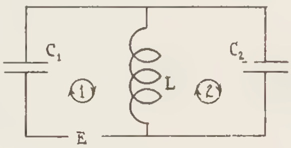


FIGURE 11.

The main circuit can be tuned to the desired frequency, ω', by means of the condenser or inductance in circuit 1. A wave trap is a condenser and coil placed in parallel and placed in the receiving aerial circuit. When the wave trap or circuit 2 is tuned to the disturbing station, signals from that station are rejected.

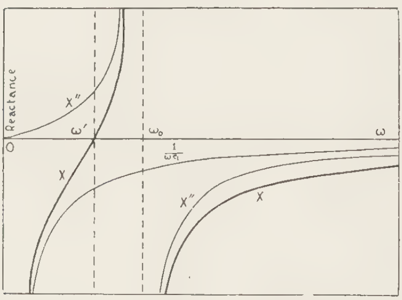


FIGURE 12.

If the circuit is as in Figure 13 where circuit 2 has an inductance, L'', as well as the coupling inductance, L, then the susceptance of

L'' and C_2 which are in series, can be found by finding the reactance as in Figure 7 for the two in series, and then taking the reciprocal as in Figure 14. The susceptance has two branches which go to infinity at the value of ω', which make L'' and C in resonance. To this add the susceptance of the coil L, Figure 14. We get a curve, S, starting from plus infinity passing through zero at ω_0 and passing to negative infinity at ω'. Then the curve comes from plus infinity and approaches zero for large values of ω.

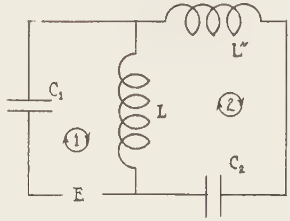


FIGURE 13.

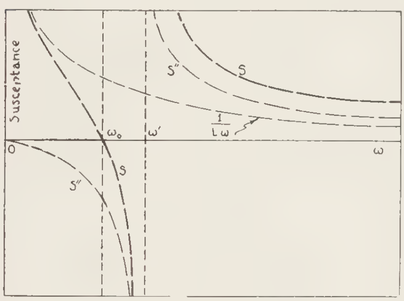


FIGURE 14.

Taking the reciprocal of the susceptance, S'', and adding $1/C_1\omega$, the reactance of the condenser, C_1, Figure 15, we have the total reactance, X, which is a line starting from negative infinity, passing through zero at ω'' and to plus infinity at ω_0, again coming from negative infinity at ω_0, passing through zero to the right of ω', at ω_2', and then passing to positive infinity at infinity. Thus we have the reactance zero at two values of ω, namely, at ω'' and ω_2'. A coupled circuit in general has two natural frequencies.

We have worked out the case of inductance coupling. Capacative coupling can be shown to give the same general results if we make our susceptance and reactance diagrams in the same general manner as worked out in detail for coil coupling.

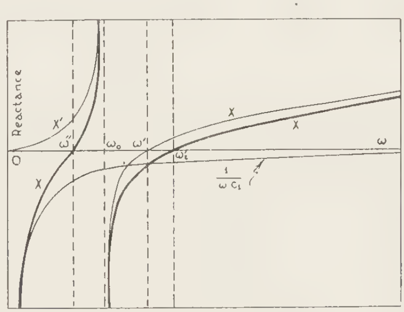


FIGURE 15.

205. Transformer Coupling. In Figure 6 we have shown two circuits and we have said that they were equivalent if $L = L_m' = L_m'' = M$. It will be seen that this is the case when all the inductance is in the coupling coil. In a transformer coupled circuit the coupling inductance, M, can be easily changed by moving the two circuits apart or by other means. The self-inductance in the two circuits remains constant as the coils are moved or as the coupling is loosened so that the constants of the two circuits remain the same.

If in a coil coupled circuit like that in Figure 6a, we are to loosen the coupling and still keep the frequency of the individual circuits constant, we must have a method of diminishing the value of L, and adding inductance to L' and L'' in such a manner that the total self-inductance in each circuit remains fixed. It will be seen that transformer coupled circuits are much more convenient when it is desired to change the coupling and not change the constants of the two circuits. In general, the value of the mutual inductance, M, is smaller than the total inductance in the circuits, so our reactance and susceptance diagrams will be like those in Figure 15, instead of those like Figure 12. There will be, in general, two frequencies with a transformer coupled circuit and the diagram in Figure 15 will apply. If a coil, L', Figure 6a, is in the first circuit, the reactance of this coil can be added to the reactance of that given in Figure 15. The reactance of the coil will be positive and represented by a straight line from zero in the diagram. Adding this to the reactance in Figure 15 will give curves of the same general shape. The position of ω'' and ω_2' will be shifted a little but there will still be two frequencies.

206. Coupling Coefficient. The amount of coupling, as has been pointed out, depends upon the relative values of L to that of the total inductances, L_1 and L_2 in the circuit, Figure 6, or upon the ratio of the mutual inductance, M, to the total L_1 and L_2.

In general, the amount of coupling depends on the coupling reactance, X, to the reactances of the circuits, X_1 and X_2. The coupling coefficient $k = X/\sqrt{X_1 X_2}$. The letter X here stands for the reactance in the circuits, whether positive or negative. If X is positive in the coupling, X_1 and X_2 are positive reactances in the two circuits. Thus $k = M\omega/\sqrt{L_1\omega L_2\omega} = M/\sqrt{L_1 L_2}$ in the transformer coupled circuit.

$k=L/\sqrt{L_1L_2}$, in the coil coupled circuit of Figure 6a. If the circuit is capacitative coupled, Figure 2,

$$k=\frac{(1/C\omega)}{\sqrt{(1/C_1\omega)(1/C_2\omega)}}=\frac{\sqrt{C_1C_2}}{C}\,.$$

In the diagrams we have shown that there are, in general, two values of ω, in coupled circuits. Since $\omega=2\pi n$ and $\lambda=v/n$ we can say that there are two values of n, or that there are two wave lengths to which the circuit responds. Since $\lambda=1884\sqrt{LC}$ in a simple circuit, the equation of the wave length, λ, in a coupled circuit can be written $\lambda=1884\sqrt{CL(1\pm k)}$. Since $k=M/\sqrt{L_1L_2}$, k depends on the value of the mutual inductance, M. If $M=L_1=L_2$, the coupling coefficient, k, is equal to unity and then the two values of the wave length, λ, are $1884\sqrt{2LC}$ and zero. In diagram, Figure 12, there is only one value where the reactance is zero, or one point where the curve, X crosses the zero line. The reactance is also zero at the point where ω is equal to infinity. This is the point where the reactance of the condenser, C_1, and the reactance of the parallel circuit are both zero.

In order that the mutual inductance of a transformer be equal to the self-inductances of the coils, the coils must be exactly alike and all the flux from one coil must go through the other. This is very approximately true if the like coils are wound on an iron core.

In an ordinary iron core transformer the value of the mutual inductance is equal to the square root of the product of the self-inductances of the coils. Thus in an iron core transformer, or in one in which there is no leakage flux, the coupling coefficient, k, is unity.

When the value of M becomes very small, or when k approaches zero, both values of the wave length approach the same value. If both circuits are tuned to the same wave length the current in the second circuit is that due to an E.M.F. induced in the coil by the small mutual inductance. The frequency of this E.M.F. is the same as the frequency of the current in the primary circuit The maximum current in the secondary circuit will be obtained when the circuit is tuned to the frequency of the primary circuit.

When the two circuits are tuned to the same frequency and the coupling is increased, the current in the secondary circuit increases

and then becomes constant. If the coupling is still increased it is found that there are two frequencies. For sharp tuning the coupling must be rather loose. The diagram, Figure 16, gives the variation of the wave length as the coupling is increased. Diagram, Figure 17, gives the change of wave length when the two circuits are tuned to different values. There is a certain value of the coupling which make the two values of λ nearest together.

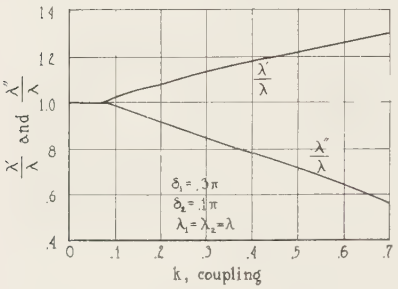


FIGURE 16.

207. Resonance Curves. If we have a coupled circuit, Figure 6b, energized by a spark discharge and bring a wave meter near the circuit, a milliammeter in the wave meter circuit will show a current when the wave meter is tuned to the right value. If the wave meter is tuned for maximum current and the coupling is decreased to a value such that the maximum reading is not greater than the maximum reading of the milliammeter, readings of the current can be made as the wave meter condenser is varied from small values of capacity and small current and up to values giving maximum current, and to large values of the condenser such that the current is near zero. If these readings of current are plotted against the angular velocity, ω, we have what is known as resonance curves. Instead of ω, frequency, n, or wave length, λ, or even the condenser dial reading can be used as abscissas and the curves will look alike. When the circuits are closely coupled there will be two points of maximum current or two humps or peaks in the curve. As the coupling is loosened the two peaks are found to come together and finally coalesce into one peak. When the

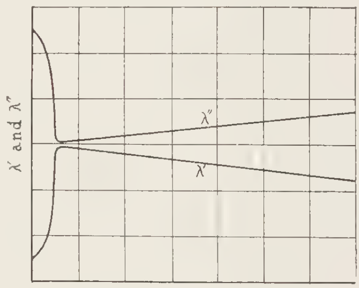


FIGURE 17.

circuit is adjusted so this one peak is very slim, we say we have sharp tuning. Figure 18 gives characteristic resonance curves for various amounts of coupling. For these readings there should be enough power in the circuits so that the wave meter is coupled very loosely The current in the main circuit should not be affected appreciably by the tuning of the wave meter.

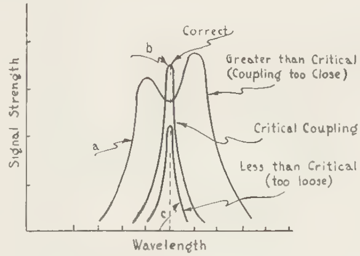


FIGURE 18.

208. Effect of Resistance on Resonance Curve. In a simple circuit the minimum impedance is equal to the resistance of the circuit. If the reactance of the circuit is equal to the resistance the current will be reduced to one-half of the maximum value. Thus if the resistance is large, there will be a relatively slow change of the current when the reactance is varied by changing the capacity in the resonant circuit. Figure 19 shows the variation of resonance curves with resistance.

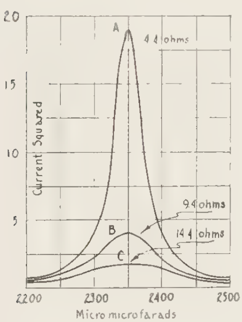


FIGURE 19.

209. Modes of Vibration of Coupled Circuits. In a transformer coupled circuit containing a condenser and a spark gap for generating damped waves, the energy is first in the primary circuit. This energy is absorbed by the secondary circuit and there comes a time when the energy is mostly in the secondary circuit. This is reabsorbed by the primary and again given to the secondary circuit. Figure 20 gives a diagram illustrating this action. Figure 21 gives the mode of vibration

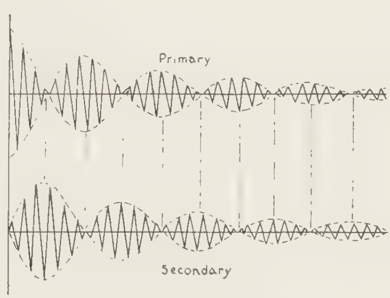


FIGURE 20.

of a circuit having a quenched gap. This action is illustrated and explained by the coupled pendulums of Figure 9, Chapter XXIII.

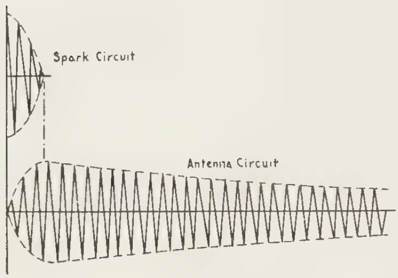


FIGURE 21.

210. Coupled Circuits Energized by Vacuum Tube Oscillators. If a vacuum tube oscillator is coupled closely to a second circuit and the second circuit is tuned in an attempt to get maximum current, the current will increase gradually until suddenly the ammeter drops toward zero. If the circuit is tuned again the current increases again, indicating that the wave length of the oscillator has a new value. Tuning again increases the secondary circuit until the oscillator breaks or flops again. The generator flops between two values. Figure 22 indicates the readings of the meter. If the curves are filled in to make smooth curves we will have a

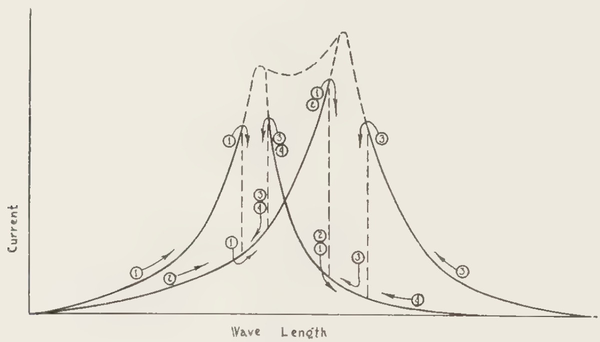


FIGURE 22.

curve with two peaks, as in a coupled circuit. In coupled oscillating tube circuits the oscillator has two modes of vibration, but vibrates in only one mode at any one time.

If the coupling to a tube generator circuit is too close, the tube may flop from one wave to another without warning. In

Figure 22 we have a curve illustrating the action of the oscillating tube when closely coupled to a circuit. If the wave length of the secondary circuit is increased from small values to larger values, we have two conditions. If the oscillator happens to be oscillating on the shorter of the two possible waves, we have the condition marked as path (1). The current increases to a certain point where the oscillator flops to longer wave length, and the current drops to the second resonance curve. As the wave length is increased the current increases and then flops to lower values and decreases as the wave length is increased. This is shown in the path marked (1). Should the oscillator be oscillating on the long wave as the wave length is being increased, the path (2) will be followed with one flop. Coming from the right to the left in the diagram there are two paths (3) and (4) which are possible.

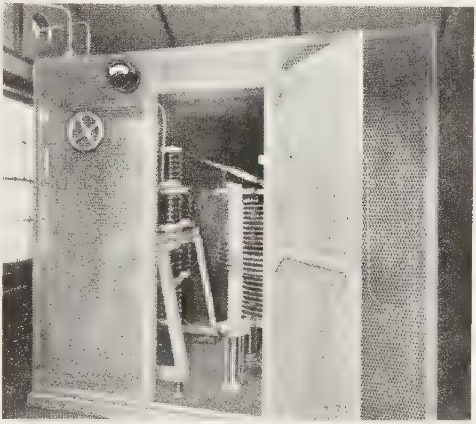


Figure 23. Antenna Coupling Equipment in the Coupling House under the Antenna at Station 3XN.

CHAPTER XVI

HOW RADIO MESSAGES ARE TRANSMITTED BY THE ETHER

211. Essentials. In radio transmission there are three things essential: A sending station to create a disturbance, a medium to carry this disturbance from the sending station, and a receiving station to tell when the disturbance goes by. Let me use an analogy to illustrate.

212. Water Wave Analogy. I shall have to ask you to use your imagination. Imagine that two boys have gone fishing. The fish will not bite and the boys have given up. Imagine that Boy No. 1 has tied a heavy chunk of wood on to the end of his fishing line and is causing the chunk to bob up and down on the water. This up and down action makes waves on the water which go to all parts of the pool in ever widening circles. Boy No. 2 is at some distance on the other side. He is endeavoring to feel the slight jerk of the cork as it bobs on the water and thus tell when the waves which his partner has sent out pass.

If the boys have previously agreed that a certain number of waves mean a certain thing; that is, if they have a code, they have all the essentials of a wireless system. They have something vibrating to create waves. They have a medium, the water, to transmit the waves from one point to another, and they have a more or less delicate contrivance to tell when the waves go by. These three things are all you need in a radio station. If you were there you could see the chunk of wood vibrate, you could see the waves on the water move across the pond, and you could perhaps see the light cork vibrate. You could count the number of vibrations per second which the float made. You could measure the distance between the crests of two successive waves or the wave length of the waves, which in this case is a few inches. You will note that the velocity of these water waves is not very great.

213. Air Wave Analogy. If on a cool morning you are looking at a locomotive which is a mile away, suddenly you see a white puff of steam and after about five seconds you hear a loud blast of the

locomotive whistle. If the pitch of the whistle is that of 100 vibrations per second, there will be about 500 waves in the air between you and the whistle. The length of the wave will be a little more than 10 feet—about 11. This wave length is obtained by dividing the velocity of sound, about 1100 feet per second, by the number of vibrations per second. In this case you can see the steam which caused the whistle to vibrate. You can hear the waves go by, but you cannot see them, since you cannot see the air. The whistle is the sending station, the air is the medium which carries the waves, and your ear drum is the receiving station.

214. Light Wave Analogy. Our forefathers in colonial days used waves to transmit their signals. They built signal fires on a high hill. The fire caused something in the atoms to vibrate. This vibration set up waves in the ether. These waves as they passed by caused a sensation in the eyes of the distant observer. We call these ether waves, light. The ether is a medium which pervades all space. We cannot see, hear, taste, feel, or smell the ether. We become conscious of its presence only when we study light and electric wave transmission. We can measure the wave length of light and of electric waves. Therefore, we conclude there must be some medium to transmit light and electric waves. We call this medium the ether of space. The velocity of light is three hundred million meters per second, or 185,000 miles per second, a distance equal to seven times around the world. Although the velocity is very great, the vibration frequency of light is so great that the wave length of light is a very small fraction of an inch.

The human being is equipped with a delicate receiving apparatus for sound waves and also for light waves. Our ears are tuned for a large number of wave lengths of air waves—but not for all possible wave lengths. Our eyes are also tuned for a large number of wave lengths of light or ether waves, but not for all possible wave lengths. At times there is a great deal of interference. It is hard to see a dimly lighted object when a bright light is shining nto our eyes. It is hard to hear a person speaking in a noisy room. If we could tune our eyes or our ears to the particular wave length we wish to receive, a large amount of the interference produced by a glaring light or a noisy room could be avoided.

In mechanical receivers for sound the receiver is many times more sensitive if the natural frequency of the receiver is the same

as the frequency of the sending station or sounding body. Take two tuning forks which are exactly alike. Strike one and hold it a few feet from the second. Stop the vibrations of the first and the second will be found to be vibrating. The sending station and the receiving station are both tuned to the same wave length—about four feet, or one and a quarter meters if the forks are middle C forks.

Take the fork to the piano, hold the damping pedal down and strike the fork. A sound of the pitch of middle C will be heard coming from the piano. If you examine carefully you will find that the only string vibrating is the middle C string. Each string on the piano board will respond to or detect a note of a certain pitch or wave length. The long heavy wires will respond to long air waves, while the short fine wires will respond to the short air wave lengths.

The sensitiveness of the sound receiving station is much increased when it is tuned to the wave length of the sending station. The electric circuit is tuned by changing either the capacity or the inductance of the receiver.

You are changing either inductance or the capacity of your receiving circuit when you twist the knobs.

215. Vibrating Electricity. In a radio transmitting station we have electricity vibrating or oscillating in an electric circuit. One of the essential parts of this circuit is the aerial. An aerial is essentially a condenser and an inductance. In Figure 1 it is easy to see that the "flat top" of the aerial, together with the ground, is a condenser. From the ground we have a wire which has inductance and perhaps a coil. Thus this circuit is nothing more than our wave meter circuit. The electricity oscillates up and down the high aerial and disturbs the ether which is about the aerial. We can not see electricity, so the aerial looks to us the same when transmitting as when the station is not transmitting. This oscillating electricity sets up disturbance or waves in the ether, and since we can not see the ether we do not see the waves. These electric waves travel out in all directions in ever-widening circles, the same as the waves on the pond. When passing

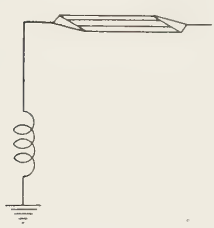


FIGURE 1.

by a receiving aerial they cause electricity to oscillate in the circuit, provided the receiving circuit is tuned to the same frequency or wave length as that of the sending station. The velocity of any wave depends upon the medium and not upon the source of the disturbance. Since these waves are ether waves, and light waves are ether waves, the velocity of electric waves is the same as the velocity of light—three hundred million meters per second. The vibration frequency is relatively high, in the neighborhood of one million times per second. Divide the velocity of electric waves —300,000,000 meters—by 1,000,000, we have 300 meters as the wave length. The electricity in the aerial circuit oscillates 1,000,000 times per second when the station is tuned to 300 meters. It oscillates 833,000 times per second when tuned to 360 meters, and 750,000 times per second when tuned to 400 meters. If you are listening to a 360 meter station which is 100 miles distant, there will be about 450 waves between you and the sending station. It will take about 1/2000 part of a second for the waves to travel from the sending station to your receiving station.

You will see that a complete wireless outfit consists of something vibrating which causes a disturbance, a medium to transmit this disturbance or waves, and a delicate receiving apparatus to tell us when the waves go by. This is what the boys at the fishing pond have. Boy No. 1 is at the transmitting station. He is operating a vibrating chunk of wood. This causes a disturbance in the water. The water transmits the waves over the surface and Boy No. 2, who is at the receiving station, becomes conscious of the passing waves when they cause a slight vibration of the cork, Figure 2.

The boys' transmitter and receiver are very much alike; in fact, they are exactly alike except for size. This is true in radio transmission. The connection or fundamental circuits of the transmitter and receiver may be exactly alike. The only difference is the size of wire used and power of the tubes. This will be apparent if one examines the circuits. In the transmitter the audio frequency amplifiers are in front of the radio circuits. In the receivers they are placed behind the radio frequency circuits. The radio circuits may be exactly the same circuit, Hartley, for example in both circuits.

216. What are Electric Waves? We have said that electric waves are disturbances in the ether of space. If on a cold morning you comb your hair with a rubber comb and bring the comb near a small piece of paper, the paper will suddenly jump to the comb and perhaps after some little time the paper will suddenly jump away again. We say the electricity on the comb attracted the paper. How did it pull it? There were no strings between the two.

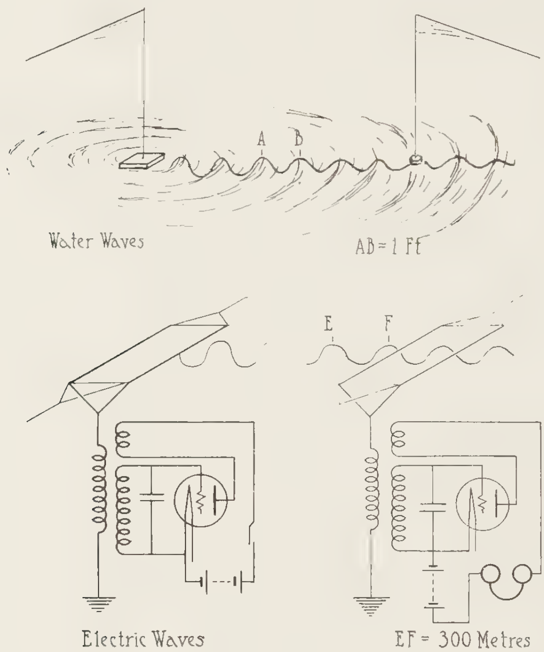


FIGURE 2.

We explain it by saying that there was an electric field between the two. No one ever saw the field. All we know is that there is an attraction between the two. If instead of paper we use more delicate apparatus such as an electroscope, we can see that these effects extend for some considerable distance from charged bodies.

If we have a ball on an insulated pole and charge it up positively we can show that another ball at a short distance is charged

negatively. Figure 3. If the charge on the first ball is changed, the charge on the second ball is changed. If we arrange to alternately charge the ball positively and negatively, the second ball will change sign of charge at the same rate, and if we have an exceedingly sensitive ammeter in the wire connecting the second ball to the ground, we will find that there is an alternating current flowing in the wire. If the frequency of alternating is very rapid and the distance between the balls is increased, the balls will not be charged oppositely. They may be always charged alike at any particular instant. This is due to the fact that it requires time for the effect to travel from the first ball to the second. If the distance is 150 meters and the frequency is one million per second, the balls will be charged exactly alike. This is due to the fact that it requires one-half of a millionth of a second for the effect to travel from one to the other.

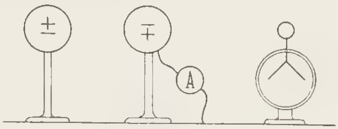


FIGURE 3.

In this time the first ball has changed sign of charge. If the distance is increased to 300 meters the balls are oppositely charged again. The charge on the second ball is due to the charge which was on the first ball one millionth of a second before.

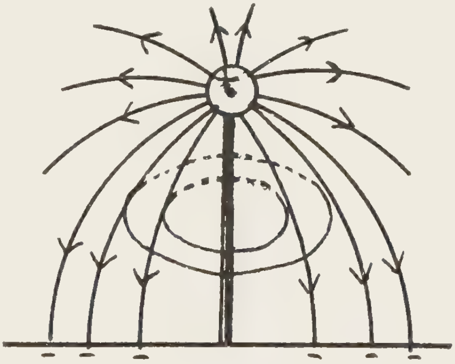


FIGURE 4.

We call the effect which causes the static charge, an electric field. This may be represented as in Figure 4 by lines which start from the positive charge on the ball and end on negative charges in the ground, perhaps. If the ball is charged negatively the direction of the field is toward the ball instead of away from it, as in the picture. If the charges alternate rapidly the field may be imagined as being as in Figure 5. As the charge on the aerial ball changes rapidly the lines of the electric field are "snapped off," and after

a short time they reach the Heaviside layer and travel horizontally between the Heaviside layer and the earth as vertical lines which are alternately up and down in direction.

217. Magnetic Field. In order to charge the aerial there must be an alternating current in the downlead of the aerial and this causes a magnetic field, which will be perpendicular to the plane of the paper. Since this is an alternating current the magnetic

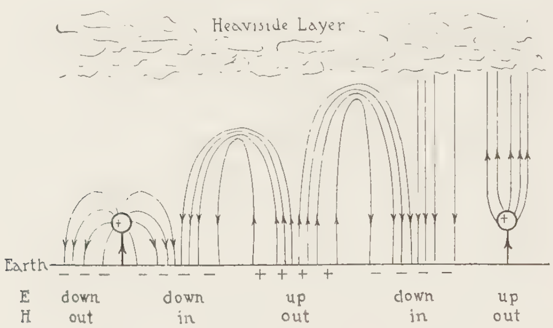


FIGURE 5.

field will be alternating and at a distance from the aerial will be in phase with the electric field. An electric wave, or electromagnetic wave, consists of an electric field and a magnetic field which are in space perpendicular to each other and which in time are in phase. We usually think of the electric field as vertical to the earth, and the magnetic field as parallel to the earth. Both of these fields are perpendicular to the direction of the velocity of the wave. The velocity in Figure 5 being from left to right, and the direction of the magnetic field is as marked under the figure, in and out of the plane of the paper.

Maximum electric field, E, being at the same place as the maximum magnetic field, H, the magnetic field, H, is the radiation field. This is explained in the chapter on Radiation and Induction. If we try to picture the fields near the aerial we will have trouble, as the field which we usually think of in connection with current electricity is induction which is out of phase with the electric vector.

At a distant point suppose that an aerial is, as in Figure 5, and at a particular instant E is vertically upwards. The aerial being a

conductor, the lines in the neighborhood end on the aerial and we have an E.M.F. which is equal to the field times the length, or $e = Eh$ where h is the height of the aerial. If we consider the magnetic field, H, as moving with a velocity, v, past the aerial, we have an E.M.F. which is equal to the number of lines of force cut per second, or $e = Hvh$. Numerically these two values of electromotive force are equal, since E and H are numerically equal and the dimensional relation of the two units is v, the velocity of light. In fact, these two, E, and H, are always associated together and in reality are the same thing—an electromagnetic wave. Two equal vectors, E and H, moving in space with the velocity of light, v, constitute an electro-magnetic wave, or electric wave, for short.

Reverse either E or H and the direction of motion, v, is reversed. To reflect an electromagnetic wave, reverse one vector, either E or H, but do not reverse both vectors.

218. How Radio Messages are Transmitted. The alternating current in the aerial creates a disturbance in the ether, the ether carries this disturbance to distant points as a wave. The waves in passing a second aerial create an electromotive force which can be detected if we have a tuned receiver of sufficient sensitivity.

219. Static. Static is caused by electrical disturbance in the atmosphere or in space. Most people when speaking of static mean any disturbance whatever which makes a noise in the loud speaker. Local disturbances such as motors, etc., and set noise can be remedied, but static is something which so far is not under man's control. The only way static has been overcome is to increase the power at the transmitter until the intensity of the signal is greater than static.

Selective receiving aerial will eliminate a certain percent. But for broadcasting reception one wishes to receive from all directions.

It has been calculated that on the average there are one hundred flashes of lightning per second on the surface of the earth. Lightning alone might account for all disturbances.

Fading is a coming and going of the signal. Not only does the intensity vary but often it can be noticed that the quality of the music changes with fading. Fading is usually explained by interference. A signal may come directly to the receiver or it may pass to the Heaviside layer and be reflected down. The two beams or

rays may meet at the receiver to interfere destructively or constructively. This will cause a change of the intensity if the lengths of two paths change in the mean time. The Heaviside layer is supposed to vary in height at times very rapidly. Fading might be explained if we receive the signal reflected from the Heaviside layer if the tilt of the layer changes. Then for certain angles the intensity will be greater than for others.

The subject of fading is one that has not been explained satisfactorily in all details.

CHAPTER XVII

RADIATION FROM AN AERIAL

220. Introduction. In Chapter XVI we have said that the electric wave is a vertical electric field and a horizontal magnetic field which are in phase and travel together. In our elementary picture of the transmitting aerial we have assumed the aerial to be a large ball at the top of a long wire. Figure 4 Chapter 16. It is convenient to think of all the capacity as being at the top or in the ball and all the inductance as being in the down wire. This is not true because both the capacity and inductance are more or less distributed in the aerial, but we will consider the simple case and then make corrections when needed. If all the capacity is at the top, all the current flows back and forth from the ground to the ball and the ball alone is charged. When the ball is charged positively the lines of electric force extend or go from the ball to the ground or into space. When the ball has the greatest potential the electricity has ceased flowing into the ball and the current is zero. When the ball has discharged to zero potential the current has the maximum value. We, of course, must assume we are dealing with alternating currents and potentials.

As stated before when the current is a maximum the magnetic field has a maximum value and we are at a quandary to see how the two fields are to have maximum values at the same time.

221. Radiation Field. In Scientific Paper of the Bureau of Standards No. 354, J. H. Dellinger has shown how the induction magnetic field, which we are accustomed to think of, is a different thing from the radiation magnetic field which we have in electric waves.

In Chapter I we have gone into the subject of fields and potentials about magnets and coils with considerable detail. The excuse for this detail is that we hope to use this in explaining the fields about coils and aerials.

Dellinger starts with a vector potential, $[i]h/x$. The line integral of a vector potential is equal to the induction, or μH. This is equal to H, since μ is unity.

The concrete conception of the vector potential and the meaning of the line integral of a vector potential is rather hard to give. We perhaps can give an idea of the line integral of an electric field. The line integral of an electric field is equal to the work done in carrying a unit positive charge of electricity. This is equal to the difference of potential or electromotive force. The line integral around a coil is numerically equal to the E.M.F. in the coil. The E.M.F. in a coil is also equal to the rate of change of flux through the coil. Thus the line integral of the electric field, E, is equal to $\mu dH/dt$.

In Chapter I we showed that the field about coils and magnets was equal to the negative space derivative of the potential or $H=-dV/dt$. Thus the field due to a coil at a point, P, is $H=2IA/x^3$ which is the negative space derivative of IA/x^2 which is the potential at the point, P.

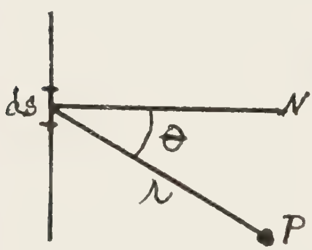


FIGURE 1.

If we assume that the general equation for field due to a current, $H=\int(Ids/d^2)\cos\theta$ applies to an aerial, Figure 1, where the height, h, is small compared with the distance between aerial and the point, P, so that the integral of ds becomes h, we can get $H=Ih/d^2$. Then $V=Ih/x$, if $d=x$. This is true since the negative derivative of V is equal to H.. In this equation the potential has the same form as Dellinger's vector potential, $[i]h/x$. However, the two potentials are not the same thing.

222. Alternating Current Fields. So far we have assumed that the current, I, is direct current or if alternating current the virtual field due to the alternating current, $\bar{I}$, is numerically the same as that produced by a direct current of the same value. Since the current in an aerial is alternating current, I must be replaced by the expression $I=I_0 \sin \omega t$. If we use this value of I in the expression for V and take the space derivative and use the "root mean square" we get the same value for H as before. This is the field which is called induction. Thus induction is the field we usually think of when we speak of self-induction, of mutual induction, of transformers and induced currents. Due to induction, energy is stored

up in the field when the current is increasing and the energy is again absorbed by the circuit when the current is decreasing. In a pure inductive circuit with alternating current no energy is dissipated. All the energy stays at home. None is radiated into space. The current is "wattless."

223. Retarded Potential. In the case of the aerial we know that the field at any particular instant is different at different positions. The field at a particular time at a particular point is due to the current which was in the aerial a fraction of a second before. The current may have reversed several times in the meantime. To take this into account we must change our equation for the current to $I=I_0 \sin \omega(t-t')$ where t' is the time it has taken for the wave to travel from the aerial to the point in question. Since $t'=x/v$ where v is the velocity of light our value of the vector potential is

$$V=\frac{hI_0 \sin \omega(t-x/v)}{x}.$$

Then

$$H=-\frac{dv}{dx}=-\frac{d}{dx}\,\frac{(hI_0 \sin \omega(t-x/v))}{x}$$

$$H=\frac{hI_0}{x^2}\sin\,(\omega t-x/v)+\frac{hI_0\omega}{xv}\cos \omega(t-x/v).$$

Thus we see that the field, H, consists of two parts. The first is the field we get by considering the current to be constant, or if alternating current, by considering the field to be independent of the sine of the angle. This virtual field is numerically the same as the field due to a direct current.

The second part is that in which we consider the angle to depend on the distance x. The two parts are out of phase by 90 degrees. We remember we had trouble with the ordinary field in our elementary picture because it was out of phase with the electric field. This second part is in phase with the electric field.

The first part is induction. The second part is radiation. The first part, the induction, diminishes as the square of the distance while the second the radiation, diminishes as the distance.

224. Virtual Fields. We can write the virtual values of the magnetic field by considering the sine and cosine to be unity, and writing I for the virtual current, then

$$\text{Induction, } H = hI/x^2$$

$$\text{Radiation, } H = hI\omega/vx.$$

If I is measured in amperes, $I/10$ will give the value of I to make the field in lines per square centimeter. Since

$$\frac{\omega}{v} = \frac{2\pi}{\lambda}$$

$$\text{Radiation, } H = \frac{hI2\pi}{10\lambda x}.$$

Equating the two values and solving for x we find that the two components of H are numerically equal when $x = \lambda/2\pi$. At a distance equal to 1/6.28 of a wave length the two values are numerically equal. Since they are in time quadrature the measured value will be 1.414 times the calculated value of one. Closer to the aerial the value of H is nearly all induction and diminishes as the square of the distance. Beyond this point the field is mostly all radiation and varies inversely as the distance.

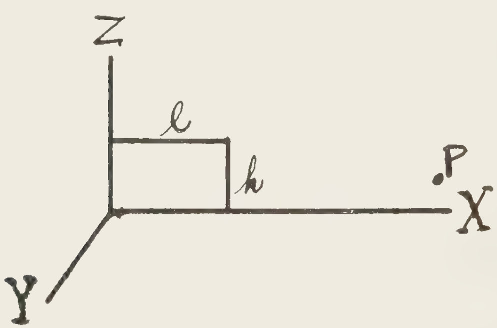


FIGURE 2.

225. Coil Aerial. If instead of an antenna aerial we have a coil aerial the induction can be calculated as has been done in Chapter I. Induction is the ordinary field due to direct current. It is found to diminish as the cube of the distance from a coil. It is $2IA/d^3$ perpendicular to the plane of the coil and IA/d^3 in the plane of the coil.

For radiation we follow Dellinger, considering a square coil in the XY plane of height h, and length l, Fig. 2. The horizontal parts will not contribute to the field at a point P in the horizontal

plane. Then the radiation at P consists of two components, one each from the two vertical wires. These two will be equal but slightly out of phase because the distance of one is greater than the other by l centimeters. The resultant field at P is the vector difference of the two equal vectors which differ in direction by a small angle, θ. $\theta/2\pi = l/\lambda$ or $\theta = 2\pi l/\lambda$. In the diagram, Figure 3, the vector oa is the vector difference of the two values of H. $oa = 2H_1 \sin\theta/2$. Since θ is small, $\sin\theta/2 = \theta/2$, then

$$oa = H = 2\pi\left(\frac{hI}{\lambda x}\right)\frac{2\pi l}{\lambda} = 4\pi^2 hlI/\lambda^2 x.$$

Thus the radiation from a coil in the plane of the coil varies inversely as the distance while the induction varies inversely as the cube of the distance.

The radiation from a coil varies inversely as the square of the wave length while from an antenna radiation varies inversely as the wave length.

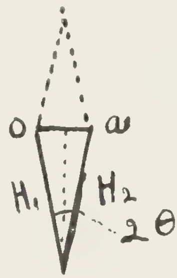


FIGURE 3.

226. Relative Induction and Radiation. We have seen, Chapter I, that the induction field from a small coil is the same as that from a short magnet if we assume that the magnetic moment of the coil is IA. The values for the field have been worked out for points end on and broadside on, Figures 14 and 15, Chapter I. For values at intermediate points the short magnet can be supposed to be resolved into two magnets at right angles to each other whose combined effect is the same as that of the original magnet. The magnetic moments of these magnets will be $M \sin\theta$ and $M \cos\theta$. One of these resolved magnets, Figure 4, will be end on to the point and the other is broadside on to the point. The coil can be resolved in the same way and the field at any point, p, is the resultant of the two fields $2IA \cos\theta/d^3$ and $IA \sin\theta/d^3$. The resultant of these two fields is $(IA/d^3)/\sqrt{1+3\cos^2\theta}$. The direction of this field is tangent to a circle whose center is in on the plane of the coil, and

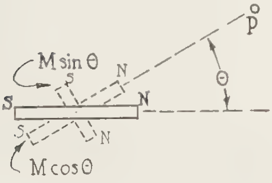


FIGURE 4.

which passes through the point, P, and the center of the coil, Figure 5.

An exploring coil must be placed with its plane perpendicular to these circles which show the direction of the field in order to get the maximum effect. Thus in Figure 5 it will be seen that the exploring coil must be turned through 180° as it is moved from the plane of the coil to a point on a line perpendicular to the coil if we wish the maximum current in the coil at all positions.

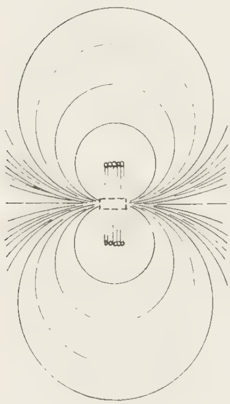


FIGURE 5.

The radiation from a coil varies as the cosine of the angle measured from the plane of the coil. Thus a circle represents the value of the induction about a coil.

The induction from a coil is IA/d^3 and the radiation from the same coil is $4\pi^2 IA/\lambda^2 d$. Equating the two values we get $1/d^2 = 4\pi^2/\lambda^2$ or $d = \lambda/2\pi$. Thus the two components are equal at a distance $\lambda/6.28$, the same being true for an antenna aerial. Close to the coil or antenna aerial the field is primarily induction.

For practical purposes when the distance is less than 1/20 of a wave length the radiation can be neglected, and when the distance is greater than $\frac{1}{2}$ wave length the induction can be neglected.

The energy represented by induction does not leave the aerial. It is stored in the medium during the first fourth of a cycle and then returns to the aerial during the second fourth of the cycle in the same manner as the field of an ordinary transformer or choke coil. The induction is the field which stays at home. The energy of the field of the radiation does not return to the aerial but passes out to infinity unless it is absorbed by intervening objects. The energy is radiated into space.

Of course it is possible to absorb a part of the energy of induction if the absorber is in the field of the induction, that is, near the aerial. This is the same as in a transformer part of the energy may be absorbed by the secondary coil in which case it cannot return to the primary.

It will be noted that radiation from a given aerial depends upon the frequency or wave length. Induction is independent of frequency. The virtual value of induction field for 60 cycle, 300 meters or 41 meters is numerically the same as that produced by direct current.

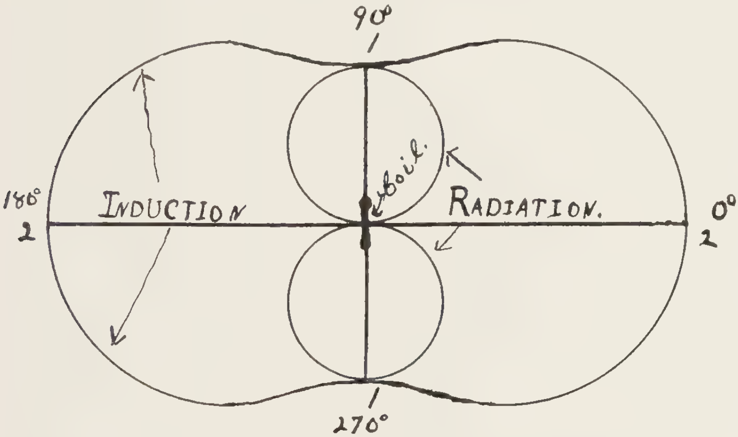


FIGURE 6. Showing the Distribution of Radiation and Induction when the distance $d = \lambda/2\pi$. In the plane of the coil the radiation and induction are equal. Perpendicular to the coil the radiation is zero while the induction is twice the value in the coil's plane.

Fig. 6 shows the relative distribution of radiation and induction when the distance is $\lambda/2\pi$. The circles show the radiation, and the "squeezed" elliptical figure shows the induction. The values are numerically equal in the plane of the coil.

Fig. 7 shows the relative values of radiation and induction when the distance is $\lambda/2$. In this case the small figure-eight figure shows the induction which can be neglected.

Fig. 8 shows the distribution when the distance is $\lambda/20$. In this case the radiation can be neglected.

If the values are of the same order, then since they are in time quadrature the effective field is the square root of the sum of the squares. If the ratio of one to the other is one to two, then the received field is $\sqrt{1^2+2^2}=2.24$. If the smaller value is neglected the error is more than 10%. If the relative values are one to four,

then $\sqrt{1^2+4^2}=4.13$. The error is 3 per cent. If the ratio is one to ten, then $\sqrt{1^2+10^2}=10.05$. The error is $\frac{1}{2}$ per cent. When the ratio is one to seven the error is 1 per cent. Taking other errors into account, one can neglect the smaller without appreciable error when the smaller is not greater than one-fifth of the larger.

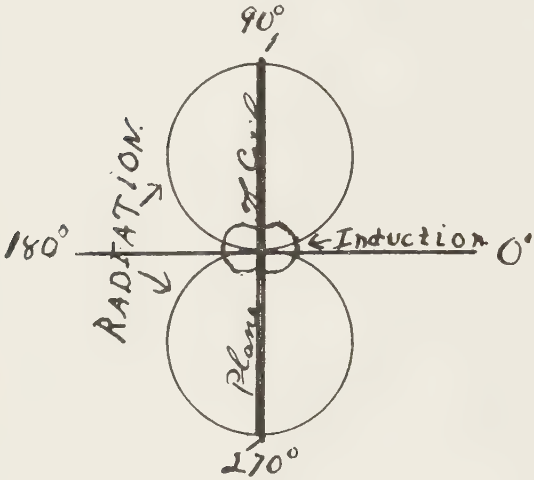


FIGURE 7.

227. Electric and Magnetic Fields are Equal. We have spoken of the magnetic field only. Maxwell's equations show that the energy of the magnetic field is exactly equal to the energy

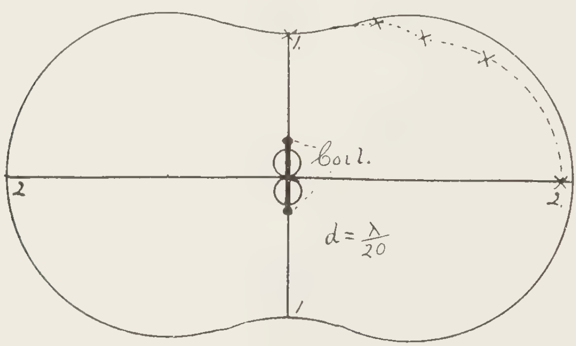


FIGURE 8. Showing the Distribution of Induction about a coil according to the equation $H=IA/d^3\sqrt{1+3\cos^2\theta}$ where θ is measured from the normal to the coil. The dotted line shows the measured values. The two small circles at the center show the relative values of the radiation when $d=\lambda/20$.

of the electric field. Thus if we know the magnetic field we know

the electric field. The electric field and magnetic fields are always associated together. They are two aspects of the same thing. They really are the same thing in a certain sense. For an illustration take a simple D.C. circuit. The current through a coil is equal to the total E.M.F. divided by the total resistance. The current is also equal to the Pd. at the terminals of the coil divided by the resistance of the coil. These two values are equal. The current in the coil is not $2I$. In the electro-magnetic system of units the ratio between E and H is 3×10^{10}. E in absolute units of potential per centimeter is equal to H in Gauss times v, (3×10^{10}).

$$E=Hv=3\times 10^{10}H.$$

If we divide by 10^8 we have E in volts per centimeter. Multiply this by 100 and we have E in volts per meter. If we reduce this to micro-volts by multiplying by 10^6 we again have $E=3\times 10^{10}\ H$ micro-volts per meter; thus $H\times v$ is either absolute units of potential per centimeter or micro-volts per meter.

E is usually expressed in micro-volts per meter written $\mu V/M$

$$E=3\times 10^{10}H\frac{\mu V}{M}\cdot$$

228. Dellinger's Equations. The E.M.F. induced in a coil by the magnetic field is $e=AH2\pi n/10$ volts where A is the area of coil and n is the frequency.

The E.M.F. induced in a vertical antenna of height h, is the number of lines cut per second, $e=hvH$ abs, or $e=Eh$ abs, or instead of absolute units the E.M.F. may be expressed in micro-volts, if h, heights, is expressed in meters instead of centimeters.

The received current can be determined by dividing the E.M.F. in volts by the resistance of coil or antenna.

From these fundamental equations Dellinger's four equations for received current can be obtained. They are:

From antenna to antenna

$$I_r=188h_sh_rI_s/R\lambda d$$

Antenna to coil

$$I_r=1184h_sh_rl_rN_rI_s/R\lambda^2d$$

Coil to antenna

$$I_r = 1184 h_s l_s h_r N_s I_s / R\lambda^2 d$$

Coil to coil

$$I_r = 7450 h_s l_s h_r l_r N_s N_r I_s / R\lambda^3 d$$

where h is the height, l is the length, N is the number of turns of coil, I is current in amperes, R is resistance in ohms, λ is wave length. The subscripts s and r, refer to the sending and receiving stations respectively. The lengths may be in centimeters, meters, feet or miles, provided all lengths are measured in the same unit. These formulae are for radiation. Induction must be calculated from other formulae.

229. Effective Height of an Antenna. The height, h, is the effective height of the antenna aerial. In the original equation, $Ids \cos \theta / r^2$, we assumed that the value of $\cos \theta$ was unity, and again we assumed that all the current flowed to the top of the aerial. Since we know the capacity at the top is distributed and not bunched, we know that the height will in general be less than the measured height. The effective height is the height of a theoretical aerial with all the capacity at the top and one in which all the alternating current flows from bottom to top and which will produce at a distant point the same field as the aerial in question. However, the distant point must not be too far removed, since there is always a certain amount of absorption by intervening objects which diminishes the intensity at a great distance. The "distant" point should be a few wave lengths removed from the aerial, one wave at least. With small power the distance may of necessity be a fraction of a wave and may be so close that the field is mostly induction field, in which case the exact distance as measured is at best an approximation. There seems to be some confusion in the definition of h. Some use h as the distance from the ground to the "top," others use h as twice this distance, arguing that the earth being a good conductor will reflect and give the same effect as an aerial in free space with the center of the aerial being the point of connection to the ground. Practically this confusion does not make much difference since the height, h, must be determined experimentally.

The height, h, is determined by winding a coil or loop of rather large dimensions or diameter, and connecting a tuning condenser and a radio frequency milliammeter in the circuit and measuring the received current when the coil is placed at a distance, d, from the aerial. The area is calculated from the formula $A = n\pi r^2$ if circular, or nhl if rectangular, n being the number of turns, r the radius of the coil, h, l, being the dimension of the rectangle. The resistance can be measured by the resistance variation method if a radio frequency resistance box is available, or by the reactance variation method if the capacity of the condenser is known.

From the received current when the coil is in resonance, and resistance of the circuit, the E.M.F. is calculated. From the E.M.F. and the area the field is calculated. From the field and the distance from the aerial and the current in the sending aerial, the height, h, is calculated, assuming the equation which gives the value of the field at the given distance. If the distance is less than $\frac{1}{2}$ wave length it will be necessary to take the induction into account.

If it is necessary to place the coil near the aerial to get enough received current to read accurately, there is a question when the distance, d, is measured. The induction from an antenna varies inversely as d^2. The center of "gravity" of the field is not at the center of the coil. Unless the distance, d, is rather great, there will be an error in placing the coil. If the radiating aerial is a coil, then the induction varies inversely as the cube of the distance and the error will be greater if the distance is measured from the center of the coils. If the distance, d, is great compared to the dimensions of the coil, the error will become negligible. Then the question arises, why not make the coil of small dimensions with a large number of turns?

We are trying to get as large value of the received current as possible. Since we are working with a particular frequency there is a maximum value of inductance which the coil can not exceed.

The received current depends upon the area, A, n times the area of one turn, and inversely upon the resistance of the coil. A little practical experience with receiving coils will convince one that with a given inductance A/R is a maximum when the coil is made with a small number of turns and large diameter—one turn if practical to handle.

Assuming we have readings which are practically correct, then the height, h, of the transmitting aerial can be calculated.

After knowing the effective height of the transmitter the field at other points can be calculated. A receiving antenna can be erected and the received current in the antenna measured as well as the resistance of the antenna. Knowing the current, resistance and field, the effective height of the receiver can be calculated from the formula $E=I/R=Hvh$, $h=I/RHv$. The height h, can be assumed to be constant for frequencies which do not differ greatly from the frequency used in the above determination. If the determination is made at 300 meters the same value of h can not be used at 40 meters.

If the antenna is a directive aerial such as an Ꞁ aerial, the field will be different in different directions. The current should be measured at several points distributed around the aerial and the mean value of h used.

230. Effective height of a Coil. The effective height of a coil is the theoretical height of an antenna in which the received E.M.F. will be the same as that received in the coil. One in which the received current is the same assuming the resistance of the coil and antenna to be the same. One can get an idea of the effective height of coils from the following table:

TABLE SHOWING CHANGE OF EFFECTIVE HEIGHT WITH WAVE LENGTH

Turns	*Area*	*Frequency*	*Effective Height*	*Wave Length*
8	88 x 88	$.6 \times 10^6$	7.8 cm.	500 meters
8	88 x 88	1.0	13.0	300
8	88 x 88	1.5	19.4	200
2	56 56	10.0	13.0	30
2	56 x 56	7.5	9.9	40
2	56 x 56	3.0	4.96	100

In the above tables it will be seen that the height of a coil is very small. This is partly overcome by the fact that as a general thing it is much easier to get a coil of small resistance than it is to construct an antenna of low resistance. A coil is also usually more portable than an antenna.

231. Radiation from Low Frequency. The question is often asked, does a 60 cycle circuit radiate? The answer is, yes and no. Theoretically, yes; practically, no. It will be impractical to get any 60 cycle current to flow in an antenna aerial. However, we can get current to flow through a coil. Assume we have a coil with 60 cycle alternating current. First we will calculate the wave length. Divide the velocity of light by 60 and we have 5,000,000 meters, or 5000 kilometers, as the wave length. One hundred kilometers is about 60 miles, so our wave length is over 3000 miles. Since the radiation and inductance are equal at a point $\lambda/2\pi$ distant, the two values are the same at a distance of about 480 miles.

The induction from a coil varies inversely as the cube of the distance. If I is the value of the induction field at a point 1 meter from the coil, the field at a distance $\lambda/2\pi$ is I/d^3. This is also the value of the radiation at that point. Radiation varies inversely as the distance. The value of R, the radiation at the coil, is then $(I/d^3)d = I/d^2$. Thus the radiation is equal to the induction field divided by the square of 480 miles, the 480 miles being expressed in meters. Thus it can be seen that the radiation from a coil carrying 60 cycle current is practically nothing. The answer to the question is theoretically, yes, practically, no.

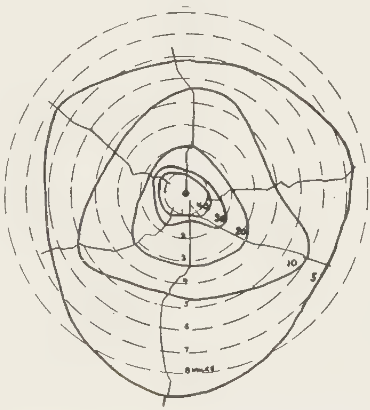


FIGURE 9. A map showing the field distribution about a broadcasting station. Published with authority from Radio Division, Department of Commerce.

232. Field Intensity Measurements. The intensity of the field is usually given in micro-volts per meter. The intensity of the field from a broadcasting station in order to be free from violent static and tube noises must be about $10000\mu\ V/m$. When the conditions are very favorable fair reception can be had when the intensity is as low as $1\mu\ V/m$.

The field intensity becomes a very important factor to the owners of a broadcasting station. The field has been found to vary in a

rather erratic manner, depending upon local conditions. Figure 9 is a map showing the distribution of intensity about a broadcasting station.

The apparatus used for measurement is essentially a superheterodyne in which the last tube is a tube voltmeter. Figure 10 is a

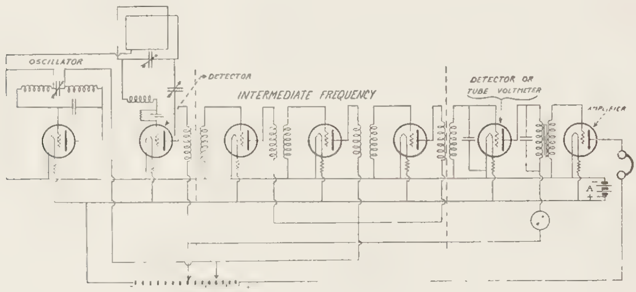


FIGURE 10.

diagram. The apparatus is calibrated by subjecting the first tube to a potential at the frequency of the measured station until the readings are duplicated.

A proposed way of doing this is to excite the receiver with the field from a small coil at a known distance from the receiver. From the current in the coil and the distance and the area of the coil the field can be calculated. This however must be done with care since reflections and other disturbances may render the readings worthless.

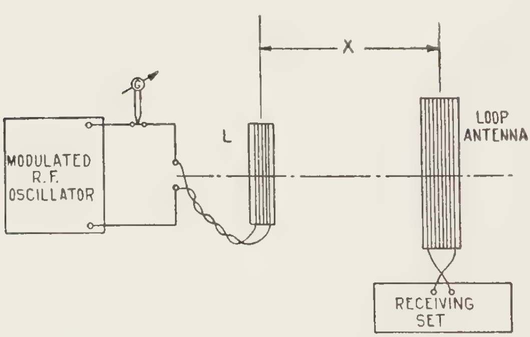


FIGURE 11. Receiving set and loop antenna. Nema Hand-Book.

The formula for the field is $E=18{,}850\ nr^2I/x^3$, where n, is the number of turns in the coil, r, is the radius of the coil in centimeters

I is the current in micro-amperes, x is the distance from the center to center of coils. The two coils are supposed to be placed parallel to each other and on a line which is parallel to the axis of both coils. Figure 11 gives a general diagram of the connections. If the coils are set with the plane of the coils in the same plane there will be radiation to contend with. See Proc. I. R. E. 16, 1118, 1928 or "Experimental Radio."

The cross points in Figure 8 give the experimental results of a set of measurements of induction close to a coil. The wave length was 700 meters.

CHAPTER XVIII

AERIALS

233. Introduction. An aerial is the device in which the oscillating current flows when the current transmits a disturbance to the ether. There are two types of aerials—antennas and coils. In Chapter XVII, Radiation and Induction, the theory of the fields about aerials is given. It remains to speak of the various types as to outward form and the characteristics of these various forms. As a usual thing an antenna is a better radiator than a coil. The coil usually has a lower resistance than an antenna and thus overcomes some of this handicap.

The antenna is sometimes called a condenser aerial, while a coil is called an inductance aerial. However, this difference is more apparent than real.

It is apparent that an antenna, especially the inverted L type, is very much like a condenser, the flat top and the ground being the two plates. Thus this is nothing but a condenser if we forget the fact that the down lead has inductance. The coil or loop is an inductance of relatively large diameter and the condenser occupies small space, but since the electromagnetic wave or the radiation is the same sort of phenomena from both, there is no real reason for the distinction. At a distance a person receiving cannot tell whether the transmitting aerial is a coil or an antenna. It will be seen that whether we have an antenna or loop aerial both are particular cases of our wave meter circuit.

The best aerial, perhaps, is a long vertical wire. The trouble is to find a structure high enough to support it. To avoid high supports, various devices are used to increase the capacity of the aerial and thus increase the wave length. In Figure 1 the T aerial, inverted L aerial, the umbrella aerial, fan aerial, etc., are all devices to increase the capacity at the top and thus increase the natural wave length of the aerial and keep the physical dimensions down to reasonable values. As a usual thing, an aerial is most efficient for waves which are near the natural wave length of the

aerial. An aerial which requires large tuning or loading coils is not so efficient.

234. Selective Radiation. A straight vertical aerial radiates equally in all directions. An inverted L aerial radiates best in the

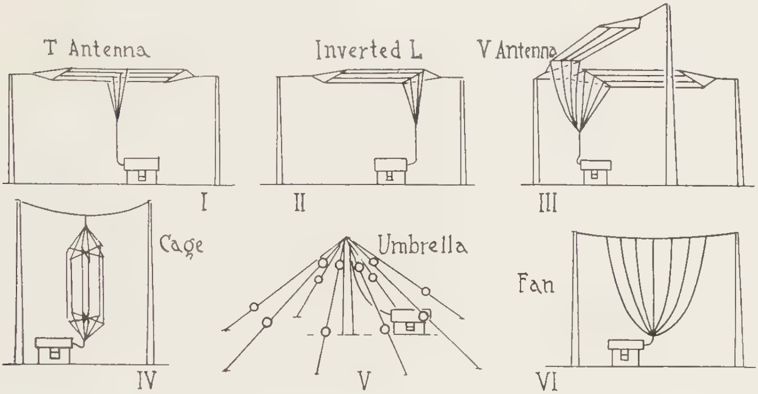


FIGURE 1.

direction opposite to that which the L points. Figure 2 is a diagram showing the directive effect of an inverted L aerial. A coil aerial radiates most in the plane of the coil and none in a direction at right angles to the plane of the coil. Figure 6, Chapter XVII. Thus coils are used as direction finders. In commercial work where a transmitter is used to work a special station, the aerials can be arranged so that a large percent of the energy goes in the special direction. Of course, for broadcast transmitters and receivers it is expected to receive and transmit to stations in all directions. Vertical aerials are theoretically suited to broadcast stations. However, most broadcast stations use inverted L or T aerials, the selectivity or directional effect being very small.

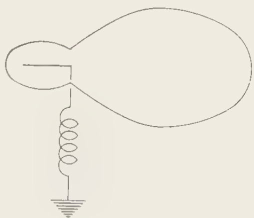


FIGURE 2.

235. Hertzian Antenna. The Hertzian antenna, originally used by Hertz in his early experiments, and which has come to some extent into practical use since short wave transmission has been developed, consists, in its simplest condition, of a copper or brass

rod one-half wave long. In practice it usually consists of two rods which have a coil of a turn or two connected between them.

The length of these rods is such that they radiate a wave whose length is about twice the combined length of the rods. The analogy of this aerial to a piano wire is very complete. In a stretched wire we can have waves set up which run to the end and are reflected. These two sets of waves, the primary and reflected, form what are called stationary waves. The frequency of these waves or vibrations depends on the length of the wire. In the fundamental vibration the frequency of the vibration is such as to make the wire one-half wave long. We have a node at each end and a loop or point of great disturbance, antinode, at the middle of the wire. In the Hertzian antenna the frequency is adjusted to the length, or the length is adjusted to the frequency so the ends are current nodes and the middle is a current loop, or a point where the current is the greatest. Figure 3a, dotted line, shows diagrammatically the distribution of current in a Hertzian rod when vibrating at fundamental frequency. Figure 3b shows the distribution of potential and current along the rod in the case of the first overtone. The current runs toward the ends and stops or is reflected, and, considering the end a condenser, the potential rises. When the upper end has the greatest positive value the lower end has the greatest negative value. The fields about the rod for 3rd harmonic are represented in Figure 3c.

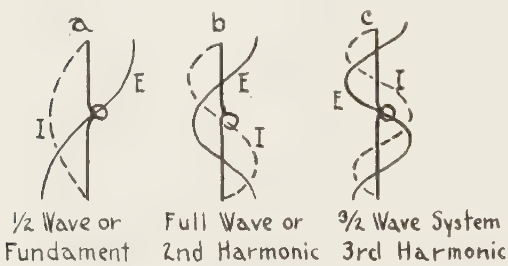


FIGURE 3.

Since the two ends are at different potentials we can think of the ends as being the two plates of a condenser and the middle portion through which the current is the greatest as being the inductance; thus we have our wave meter circuit to which we can apply our equation for wave length, $\lambda = 1884\sqrt{LC}$.

The Hertzian antenna has no ground connections, and for theoretical considerations can be thought of as being in free space.

236. Marconi Type Antenna. Marconi conceived the idea of connecting the antenna to the ground. This makes use of the conductivity of the ground and for practical purposes the radiation is increased. This is supposed to be due to the ground current. If an electric wave is a vertical field and if the lines start from positive charges and end on negative charges, there must be charges flowing along the surface of the earth since the vertical electric field moves along the earth. These moving charges constitute the ground currents. The simplest Marconi type antenna is a straight vertical wire connected to the ground. Then from a theoretical consideration the length of the wire is one-fourth of a wave length. From the table following it is seen that taking the length over all, flat top and down lead, the fundamental wave length is from three to something over four times the length.

TABLE OF NATURAL WAVE LENGTHS

Type	Length of Flat Top Feet	Height of Flat Top Feet	Total length Feet	No. of wires	Natural Wave-length	Capacity Mfds.
L	208	96	304	6	374	.00128
T	250	150	400	4	426	.00096
T	151	110	261	6	290	.0009
L	170	85	255	4	380	.00082

The rule that has been given at times for the natural wave length is that the wave length in meters is equal to the total length in feet.

237. Adjustment of Wave Length. The wave length of an aerial is increased to greater values than that of the natural wave length by placing an inductance or loading coil in the aerial near the ground connection. This increases the total inductance and the wave length is increased. It is not practical to try to increase the wave length of an aerial more than four times the natural wave length.

The wave length is decreased below the natural wave length by placing a series condenser in series with the aerial near the ground. Since the aerial can be thought of as a condenser, the

condenser in series decreases the capacity of the circuit and thus decreases the wave length.

238. Harmonic Transmission. Since the aerial can be likened to a piano string or to an organ pipe, it is possible to have the aerial resonating to harmonics or vibrating in segments. Thus it is possible to use a long aerial and to tune the transmitter to such a frequency that the aerial will respond to a harmonic of its fundamental wave length. This is often done where very short waves are used. Figure 4 shows the mode of vibration of a simple aerial of the Marconi type.

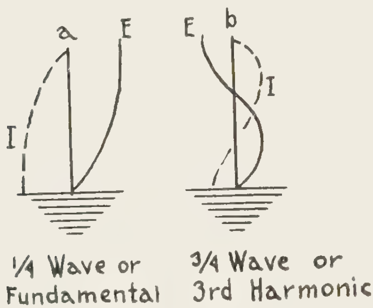


FIGURE 4.

239. Cage Aerial. In high power transmission the potential on the aerial becomes very great and at times there are brush or corona discharges from the aerial at the ends, at the points of high potential. This corona discharge is a waste of energy and the resistance of the aerial is increased. The corona discharge can be diminished by increasing the diameter of the wire. This increases the weight and wind pressure on the aerial. The corona discharge can be diminished by building the aerial into a cylindrical shell by placing several wires, six to twelve, or more, at regular intervals around circular forms so as to form a hollow cylinder or cage. This also diminishes the "skin effect" of the conductor and decreases the resistance. Sometimes the down leads or wires are built into the form of a cage. The objection to this is that the capacity of the down leads is increased, making the average height of the capacity low.

Cage aerials may be inverted L or T type, in general form. Figure 1, IV, shows a vertical cage aerial.

240. Multiple Tuned Antenna. The multiple tuned antenna as used by the Radio Corporation of America, is an antenna in which instead of one tuning or loading coil, several—six—are used. This antenna depends upon the principle of parallel resonance. Figure 5 shows the principle.

In Figure 4, Chapter IV, on Alternating Current, we have a generator and a condenser and inductance in parallel. It is shown

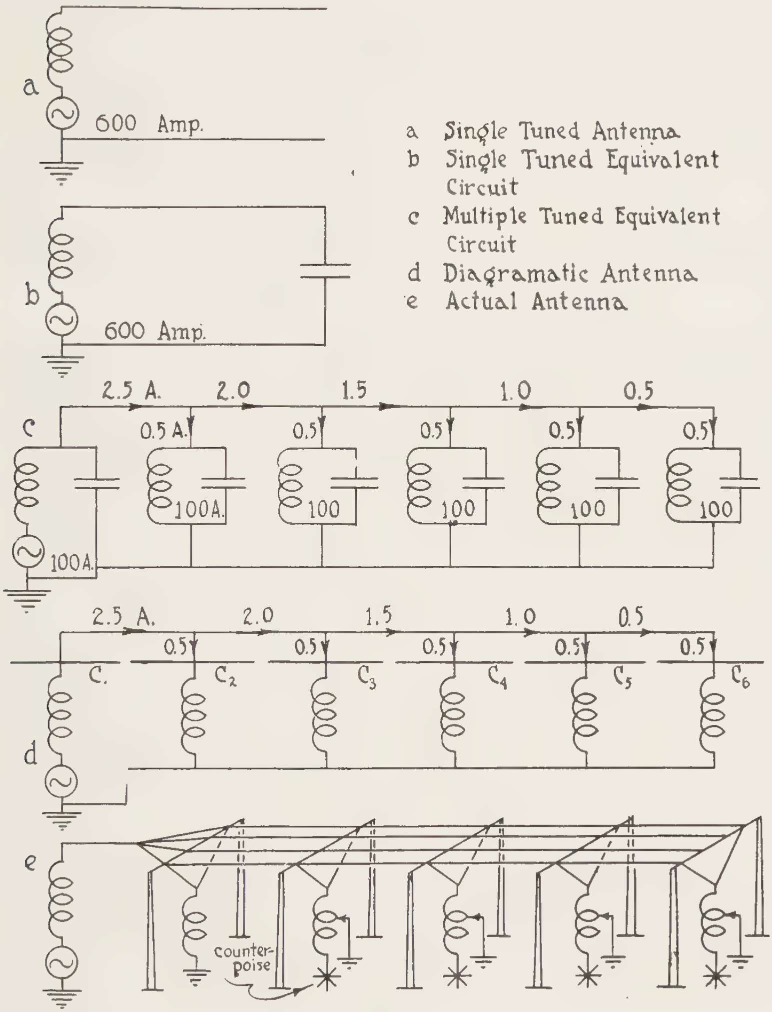


FIGURE 5.

there that a small current in the main circuit causes a large current in the parallel circuit.

In Figure 5 we have the equivalent circuit of the multiple tuned antenna in which we have the generator in a circuit with L_1 and C_1. This circuit is in series with five other multiple circuits which are in multiple. The "series" current from the circuit L_1C_1 is 2.5 amperes. This is distributed to the five parallel circuits which take .5 ampere each. This, by the principle of parallel resonance is transformed into 100 amperes in each circuit. The generator furnishes the energy, equivalent to 600 amperes, to an inverted L antenna as shown in Figure 5a. The equivalent simple wave meter circuit is shown in Figure 5b.

Figure 5d shows the same equivalent circuit as Figure 5c except the condensers are shown as being T aerials connected to the ground through the inductances.

Figure 5e is a diagram of the multiple tuned aerial. In this the tops of all the T aerials and the series feed wires are all connected together and become the flat top of the aerial.

One great advantage of this aerial is that it is connected to the ground at six points in parallel and the resistance is decreased very much—from 3.7 ohms to about .5 ohms in the case of the New Brunswick, N.J., station.

The multiple tuned aerials at "Radio Central," Long Island, consist of twelve wires spread on cross arms 150 feet long. These cross arms are supported on towers 400 feet high, the length being about one mile and a half.

Figure 6 is a picture of a multiple tuned aerial of "Radio Central," Rocky Point, Long Island.

241. Beverage Wire. The Beverage wire, is a long antenna or wire stretched in the direction from which the waves come. As the wave moves along, the current in the wire builds up, and should increase with the length of the wire if the velocity of the wave in the ether and wire are the same. Since the wave in the wire lags behind the ether wave, the two waves will eventually be out of phase, making an increase of length a detriment instead of a help. In practice the wire is only a few waves long. The intensity of the signal in the wire increases as the length, and the signal is greatest at the far end from the sending station. In the simple cases the receiver is placed at the far end. Signals coming from the opposite direction will build up to a maximum intensity at the end opposite the receiver and will be reflected back to the receiver

unless they are absorbed. A resistance is placed at the far end to absorb the signal.

FIGURE 6. The twelve 400-foot trans-Atlantic towers of the Radio Corporation's Station at Rocky Point, Long Island, N. Y.

In the simple Beverage wire as used by Godley in 1921 at Androssen, Scotland, while receiving during the Trans-Atlantic test of The American Radio Relay League, the wire was 400

meters long, two wave lengths, and stretched out toward the sea in a westerly direction toward America. The receiver was placed at the land end of the wire and a resistance of about 400 ohms was placed between the wire and the ground. In this manner signals coming from America built up and were re-received in the receiver while signals and static coming from other directions either did not build up or built up and were absorbed by the resistance at the sea end. This not only makes a directive antenna but it makes one in which a large percent of the static is cut out. Figure 7 shows the simple Beverage wire.

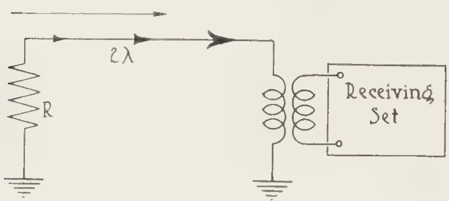


FIGURE 7.

242. Wave Antenna. Figure 8 is a diagram of the wave antenna used at Riverhead, Long Island, by the Radio Corporation of America for receiving from European stations. This consists of

FIGURE 8.

two wires nine miles long, mounted on telegraph poles. These wires serve as antennae and also as transmission lines. The signals coming from the east build up and pass through a special transformer, and to the ground at the western end. The secondary of this transformer is connected from the middle of the primary to the ground. The signals from the two wires pass through the two halves of the primary in opposite directions and thus annul any effect on the secondary. From the primary the signals pass through the secondary to the ground, and in doing so the signal is induced

in the primary and communicated to the wires in series. These wires serve then as a transmission line to the receiver at the east end. The receiver is connected to the secondary of another transformer to the primary of which the wires are connected. Thus the "transmission wire" signals affect the receiver. Signals coming from the west build up and pass through the primary of this transformer in opposite directions to a mid tap in the coil and then to the ground through an absorbing resistance. This signal is not heard on the receiver, since the two sides balance each other. Thus the receiving apparatus and the absorbing resistance, which must be adjusted from time to time, are at the same end of the line. This antenna cuts out all American stations, including the powerful stations at "Radio Central," which are sixteen miles away, and eliminates about 90% of the static. In the diagram, Figure 8 the useful signal from the east is represented by arrows made with full lines, while the absorbed signals and static are represented by arrows made of broken lines. The full line arrows represent the signal on the transmission line and in the transformers.

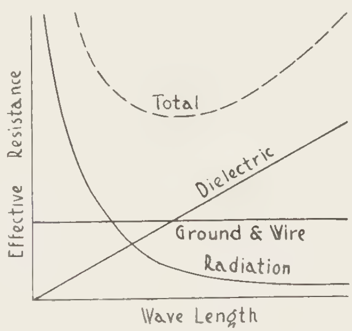


FIGURE 9.

243. Antenna Resistance. The resistance of an antenna consists of three factors. The resistance of the wire and ground connections, the dielectric resistance of the insulators and objects in the neighborhood, and the radiation resistance. This last, radiation resistance, is a measure of the useful energy.

These three resistances are represented in the diagram. Figure 9. The line which is almost horizontal represents the ground, wire, and loading coil, resistance which is nearly constant, diminishing slightly with wave length.

The dielectric resistance is due to dielectric losses in the insulators, building and other objects in the neighborhood. It diminishes as the frequency and is represented by the line which passes through zero and makes an angle with the X axis. The Radiation resistance increases with frequency and is represented

by the curved line. The summation of these three shows that there is a point of minimum resistance. Thus with every aerial there is a wave length at which the resistance is a minimum.

244. Ground Resistance. Ground resistance is the resistance which is introduced in the antenna circuit at the connection to the earth. Ground resistance depends upon the kind of soil at the point where the connection is made. The resistance of damp salty marsh land is relatively low, while the resistance of dry sandy soil is high.

In order to reduce the ground resistance it is customary to bury wires and metallic plates in the ground under the aerial. Often these wires are buried in systematic order, the wires radiating from the point where the aerial is connected. With modern receiving apparatus, small ground resistance is not of so great importance as it was in the days of the crystal detector. Amplification is often cheaper and easier to procure than a low resistance ground.

The following theoretical consideration shows that the resistance is nearly all in the immediate neighborhood of the point of connection and that distance from point to point has little effect.

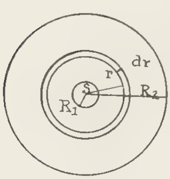


FIGURE 10.

If a good conducting sphere such as copper sphere, is placed at the center of a hollow copper sphere and is surrounded with a poor conductor such as earth, the spheres, together with an insulated copper connecting wire, may be considered as perfect conductors and then all the resistance is due to the earth. Figure 10.

Let S be a conducting sphere of radius R_1. About the center of S, draw two spheres of radius r and $r+dr$. The resistance of the spherical shell will be

$$dr = \rho \frac{\text{length}}{\text{Areas of cross section}} = \frac{\rho dr}{4\pi r^2}$$

$$R = \frac{\rho}{4\pi}\int_{R_1}^{R_2} \frac{dr}{r^2} = \frac{\rho}{4\pi}\ {}_{R_1}^{R_2}\!\left[-\frac{1}{r}\right] = \frac{\rho}{4\pi}\left(\frac{1}{R_1} - \frac{1}{R_2}\right).$$

If R_2, the radius of the hollow sphere, is very great $= \infty$ then $R = (\rho/4\pi)(1/R_1)$. All the resistance is near the small sphere and if the conducting copper sphere at the center is increased to twice the radius the resistance of the "ground" is reduced one-half.

The same ratio will hold if the copper sphere is half buried on the surface of the earth, and it will be seen that in making good grounds a large amount of metallic surface must be exposed to the soil.

In making temporary "grounds" metallic stakes are driven into the ground. If two metal stakes or pins are driven into the ground some distance apart, ten feet, say, and these two stakes are connected into the unknown arm of a Wheatstone bridge, the resistance will be in the order of a hundred ohms or more. If at each point another stake is driven and connected to the first, and a second measurement is taken, the resistance will be about one-half that with the single stake. If more are driven the resistance will be still less. If the stakes are driven to twice the depth, the resistance will be still further reduced. If the points are placed one hundred feet apart the measurements will be practically the same, showing that the extra ninety feet introduces no appreciable resistance. This is assuming that the spaces between the stakes in a group are small compared to ten feet.

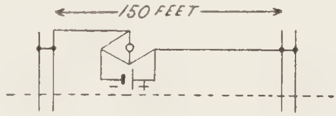


FIGURE 11.

If one considers the path of the current radiating from one station and entering the second station, it will be seen that the cross section of the conductor is practically infinite compared to the lengths and the added resistance is near zero.

Thus the resistance depends upon the surface of the connection of the metal, or on the radius of the sphere to which the stakes or metallic connections approximate. (For details of measurement see "Experimental Radio.")

245. Counter Poise. The construction of a low resistance ground is rather troublesome. If one stretches a second set of wires made up like the flat top of the aerial under the aerial and makes connections to this instead of to the ground, the measured resistance will be rather low. The counter poise should be placed about fifteen feet above the ground. Instead of placing the counter poise parallel under the aerial, if the wires are run radially from the point under the down lead, the effective resistance is much lowered.

246. Natural Wave Length of an Antenna. Distributed Capacity and Inductance. The natural wave length of an aerial should be given by the formula for the wave meter circuit, $\lambda = 1884\sqrt{LC}$, provided all the capacity and all the inductance were located at one point. But since the capacity and inductance are distributed as shown diagrammatically in Figure 12. The formula, $\lambda = 1884\sqrt{(L+L_0/3)C_0}$ gives a better value. Where L is the inductance of the loading coil, L_0 is the inductance of the aerial, assuming the current is the same at all points, and C_0 is the capacity of the aerial as measured by a capacity bridge using low frequency A.C.

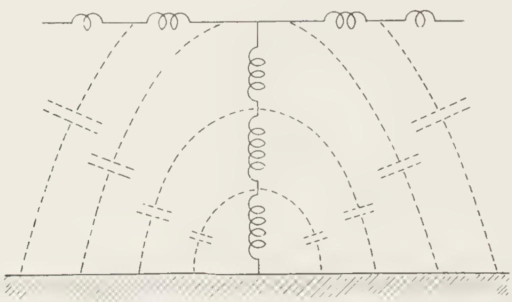


FIGURE 12.

Since all the current does not flow through all the inductance, an average value for the effect must be used.

The capacity and inductance of the antenna can be measured using wave meter methods. ("Experimental Radio," pp. 55–56.)

247. Coil Aerial. A coil aerial as shown by the formula for radiation in Chapter XVII, is a poor radiator, since the radiation varies inversely as the wave length cubed. This is made up to some extent by the fact that it is rather easy to construct a coil or loop with low resistance.

Coils are not used to any extent as transmitting aerials except for short waves, when transmitting short distances. A coil as usually built consists of a few turns of wire spaced rather far apart. Thus the distributed capacity of the coil is rather low. The wave length of the coil can be calculated fairly accurately by the usual formula, $\lambda = 1884\sqrt{LC}$.

Coil aerials can be used on superheterodyne receivers, since the amplification of this type of receiver is very high. However, the signal comes in much louder if an antenna aerial is connected to the set thus showing the fact that the antenna aerial is much more efficient.

248. Direction Finders. The field from a coil is in the plane of the coil, the radiation perpendicular to the plane of the coil being zero. Thus coils are used as direction finders. The coil is rotated to the position of zero signal and then the signal or wave strikes the coil perpendicular to the plane of the coil. There are thus two directions, east or west, say, from which the signal may come. A second reading taken at a point some distance from this position and at right angles to the direction will give the location. The exact location can be found by the method of triangulation. Reflections from near objects will make the readings taken at some places of no value, especially with short waves. Trees, buildings and hills have their reflecting or reradiating effects. It is practically impossible to locate an arcing, radiating transformer or other electrical device by this method, since all the wires connected to this apparatus act as antennae.

The direction from which a signal comes can be determined by placing a vertical antenna on one side of the coil. The antenna and the coil may add their effects and make the signal strong. If the coil is turned around the polarity of the signal is reversed in the coil. The polarity of this signal from the antenna will be in the same direction as at first. Thus the signal will be weaker. From this effect the operator knows whether the signal came from east or west.

249. Selection of an Aerial. Several things enter into the selection of the type of aerial to use in any case. One of the things which have a great deal to do with the case is space. This is especially true on ship board. On small ships the distance between masts is short and an inverted L type gives the longest natural wave length for the space, so the inverted L antenna is generally used. In many of the land stations the inverted L is used. Probably after the inverted L, the T type is the most common except in short wave work where the Hertzian type is often used.

250. Receiving Aerials. In many of the commercial and ship stations the same aerial is used both for receiving and transmitting. A change-over switch is used to change the connections from the transmitter to the receiver.

In the larger stations, such as trans-Atlantic stations, a separate aerial is used. This is usually located some miles from the transmitter. These stations transmit and receive from definite foreign

stations and by this means two-way transmission is carried on at the same time.

The actual receiving and transmission, keying, is done many miles from either transmitter or receiver. All receiving and transmission of the trans-Atlantic stations on the Atlantic coast of the United States is done from the same building in New York City. Ordinary telegraph lines carry the messages to and from the stations proper and New York.

In the modern receivers which use several stages of amplification the selection of a receiving aerial is not such a problem as it was some years ago. In the days of the crystal detector, all the energy used came from the transmitting station and an efficient aerial, one with low resistance and one which had a good location was of great importance.

251. Broadcast Receiving Aerial. As a usual thing the length and height of a receiving aerial depends upon the convenience or ease of finding suitable supports of the aerial. The aerial is usually a single wire strung from trees or buildings. The usual dimensions recommended are, a wire about 100 feet long placed 30 to 40 feet high. It is claimed that a greater height will increase the intensity of signal but increases the intensity of static at the same time, the height for the best ratio between signal and static being 30 to 40 feet. Loud signals are of no importance if the static is louder

252. Aerial Wire. For receiving aerials the kind of wire is of little importance. Most of the resistance is usually in the ground connection, and a few ohms more or less in the wire makes little difference. Solid copper wire with the joints well soldered is all that is needed. Stranded wire is more flexible and is usually easier to string up.

CHAPTER XIX

RADIO FREQUENCY INSTRUMENTS AND APPARATUS

253. Radio Frequency Apparatus Compared with Direct Current Apparatus. For direct current measurement we have as the fundamental instrument the galvanometer. As special cases of the galvanometer we have the ammeter and the voltmeter. The ammeter is a special galvanometer whose resistance is near zero, usually assumed to be zero, and so adjusted and calibrated that one division on the scale represents one unit of current.

The voltmeter is a high resistance galvanometer which takes little current, usually assumed to be zero current, and so adjusted that one unit of potential gives a deflection of one division on the scale.

In using ammeters and voltmeters we usually make the above assumptions, but if these assumptions are not complied with our readings are not true.

The fundamental current measuring instrument for radio frequency current is the hot wire galvanometer or ammeter. It is convenient if we can make the same assumptions about these radio frequency current instruments which we usually make about D.C. instruments. The hot wire instrument depends on the heating effect of the current in a wire. The heating is proportional to I^2R. The wire must have resistance, and this resistance is usually large compared to that in a D.C. ammeter, so as a usual thing we must be more careful about assuming the resistance of the ammeter to be zero. In most R.C. circuits we cannot assume that the current with the ammeter in the circuit is the same as that with the ammeter out of the circuit.

In R.C. circuits inductance plays a very large part. Even a straight wire has inductance and for very high frequency this is enough to affect the circuit. In general, a circuit will need retuning after an ammeter has been inserted. Again, the resistance of the ammeter must be constant. The heating effect depends on the I^2R effect, thus the resistance, R, must be constant for

all frequencies if the instrument is to read correctly for all frequencies. In order to have a resistance which is independent of frequency, we must have a wire of very small diameter, Chapter XX.

The fundamental definition of one ampere R.C. is that radio frequency current which produces the same heating effect in a wire as one ampere D.C. Thus the ammeter must be calibrated with direct current and when we get the same deflection with R.C. as that produced by 1 ampere D.C., we call the value of the current 1 ampere R.C.

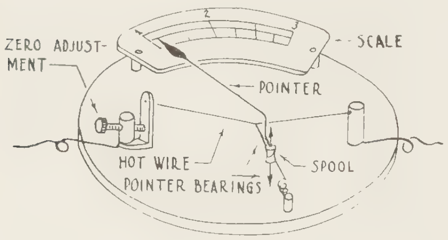


FIGURE 1.

A radio ammeter is made of a thin wire placed so as to be nearly straight with some kind of a mechanism to indicate the expansion of the wire. Figure 1 gives a diagram of the mechanism. The wire is kept stretched by a spiral spring, which is attached to small glass beads through which the wire passes. Attached to the same bead is a fine thread or hair which in the simplest case is wound around the spindle to which a hand is attached. This hair is kept tight by the small spring.

This instrument may be calibrated to read directly, in amperes or milliamperes.

254. Current Squared Instruments. The instrument may have a scale of equal divisions. This then reads proportional to the heating effect and is said to be a current squared instrument. These current squared instruments are called radio frequency galvanometers or wattmeters. The name wattmeter has largely gone out of use since the reading is proportional to the energy and can not be calibrated to read watts. I^2R is watts, so the energy depends upon the value of R, the resistance of the circuit. The instrument might be calibrated to read watts in one particular circuit, but not for all circuits.

255. Thermo-couple Instruments. A thermo-couple instrument consists of a wire through which the current passes, and a thermocouple to measure the temperature of the wire. Figure 2 is a simple diagram illustrating the principle.

The radio frequency current flows through the wire and a junction of two metals, copper and constantin, placed near or in contact with the wire. The wire is heated by the current which heats the junction and a D.C. galvanometer measures the E.M.F. of the junction. The deflections are proportional to the square of

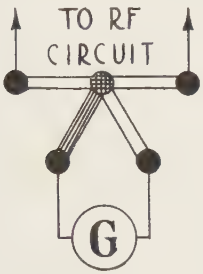


FIGURE 2.

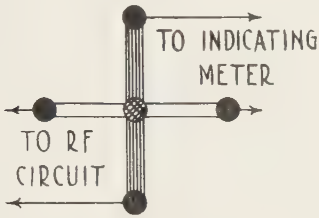


FIGURE 3.

the current. The same precautions must be taken to keep the resistance constant and the inductance low, as in the hot wire instruments.

The junction is usually in contact with or welded to the heater wire, and often the junction circuit through the galvanometer acts as a shunt around a small portion of the wire. With direct current through the heater the D.C. galvanometer deflection may be largely due to this shunted current. If D.C. current is passed through the heater and then reversed the two deflections are not the same. Unless the direct and reversed deflections are the same, 60 cycle alternating current must be used to calibrate the instrument. The 60 cycle current through the D.C. galvanometer will give no deflection. In some instruments two dissimilar wires are crossed and welded together, as in Figure 3. In this case the two terminals are connected to the high frequency while the other two terminals are connected to the galvanometer. It will be

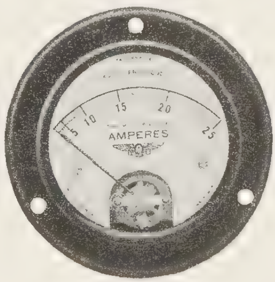


FIGURE 4

evident that the scale on the galvanometer can be so drawn as to read milliamperes or amperes directly. Figure 4 is a Jewel ammeter.

256. Large Ammeters. An ammeter to carry large current cannot be made with a heater consisting of a single small wire. One type of meter is one in which a number of small wires are soldered to the circumference of two heavy discs forming a cylinder or cage. Thus the current capacity is increased by the number of wires. Unless the wires are very small the resistance of one wire will be changed by the presence of the others. The junction is placed in contact with one of these wires. Figure 5 shows the principle. The meter is calibrated with 60 cycle current. Another type is the transformer type, Figure 6. Since this has a turn of wire, it can not be used at very high frequency.

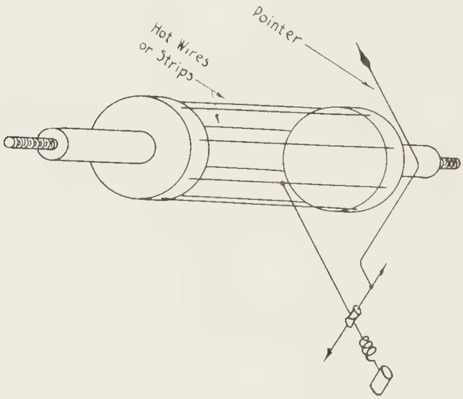


FIGURE 5.

257. Meters for Small Current. Self-contained ammeters and milliammeter instruments in which the D.C. instrument and heater are all in the same case, are usually not made to read maximum current of less than 100 milliamperes. 20 milliamperes is about the smallest current that can be read with any accuracy. For smaller current special thermo-junctions incased in glass and evacuated, are used. These junctions are used with sensitive galvanometers or microammeters. They must be

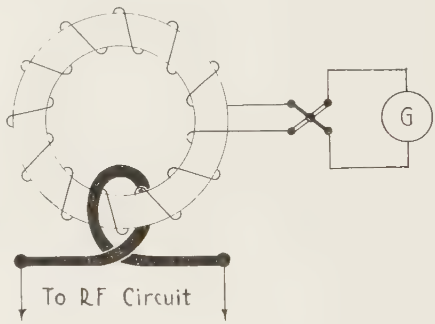


FIGURE 6.

calibrated for each galvanometer or micro ammeter used. It is possible to get a junction which will measure one milliampere with considerable accuracy but the resistance of the heater of the junction will be rather large—100 to 1000 ohms. Thus, it will be seen that, the resistance of the meter must be considered. Where the junction is used to measure the A.C. component of

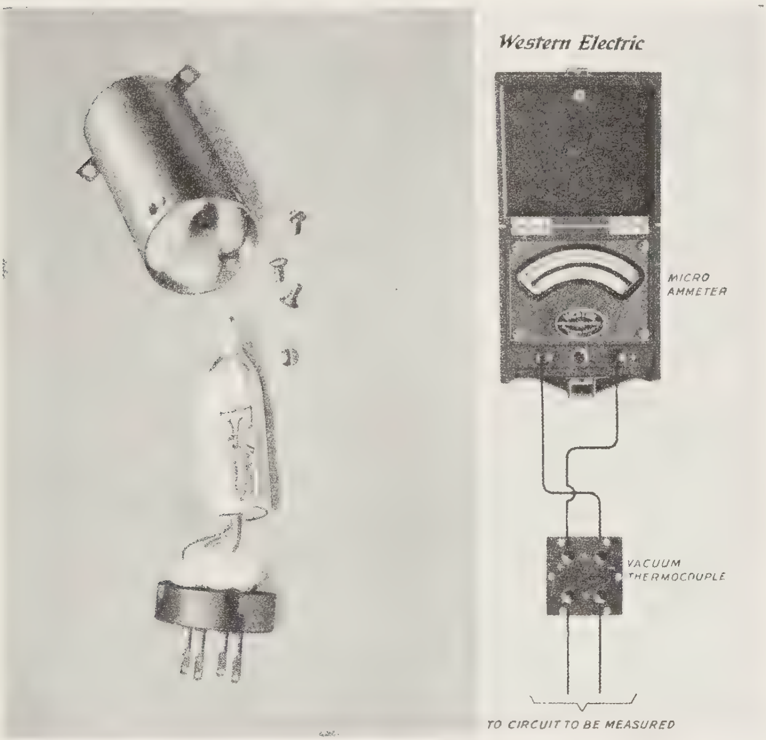


FIGURE 7.

the current in the plate circuit of a tube, this resistance will not be so important. Junctions whose heaters have one or two ohms resistance can be obtained which will measure current of ten milliamperes with considerable accuracy when a sensitive galvanometer is used. Figure 7 shows a Western Electric junction.

258. Radio Frequency Voltmeters. Since a voltmeter must take little current, radio frequency voltmeters are hard to construct. Where the current in the circuit is large a voltmeter can be made of a junction, or a milliammeter and a high resistance. This resistance must be a radio frequency resistance in order that the value can be known with certainty. If the resistance is known and the current is known by the meter deflection, the potential at the terminals can be calculated. If the resistance is adjustable the proper resistance can be calculated and inserted to make the instrument read volts direct. If the instrument reads directly in milliamperes, a total of 1000 ohms makes one milliampere correspond to one volt. Then the reading in milliamperes can be called volts.

In many circuits the current taken by the meter will be large enough to change the circuit, rendering the readings meaningless. If such a meter is placed around a condenser in order to measure the potential across the condenser, the power used by the voltmeter changes the circuit until the readings are worthless.

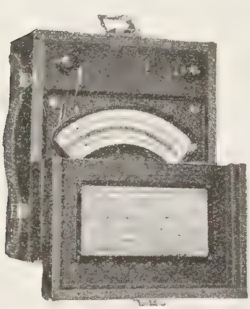


FIGURE 8

On account of the trouble with voltmeters, most measurements were formerly made without recourse to a voltmeter. Power is usually calculated in terms of I^2R, where R is the resistance of the circuit. This resistance is measured by the resistance variation method or the other methods. Thus the energy radiated is calculated in terms of radiation resistance. Figure 8 is a Weston radio frequency milliammeter.

259. Vacuum Tube Voltmeters. There have been several types of vacuum tube voltmeters proposed. The various types usually depend upon the rectifying or detecting properties of the vacuum tube. As a usual thing the currents in the circuits to be measured are so small and the adjustment of the circuits to resonance is so critical that an ordinary type voltmeter, milli- or micro-ammeter, with resistance in series can not be used.

In using a vacuum tube voltmeter certain assumptions are made therefore the voltmeter gives erroneous results unless these assumptions are fulfilled.

The above is true with D.C. voltmeters. When using a D.C. voltmeter we usually assume that the voltmeter takes little or no current and that the potential at the terminals of the voltmeter is the E.M.F. measured. A simple case will illustrate. Suppose we have a cell—old dry cell. If we measure the E.M.F. by means of a potentiometer and a standard cell we get a value near the standard value. If we use a good voltmeter we may get a result which is a fraction of the former value. The reason for this is that the battery has considerable resistance and one of the fundamental assumptions made when using a voltmeter is that the resistance of the voltmeter is so great that the battery resistance can be neglected.

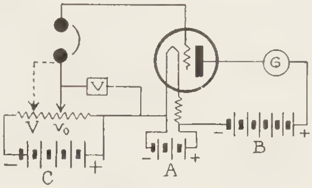


FIGURE 9

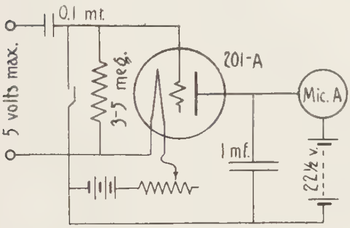


FIGURE 10.

One of the assumptions made when using a vacuum tube voltmeter is that the voltmeter does not load the circuit or change the constants of the circuit. The load ais relative term and a load which can be neglected in one case is prohibitive in another case. In certain cases the capacity of the tube will have an effect. Care must be exercised in the use of the vacuum tube voltmeter. It will be impossible to point out all the pitfalls, but one must be on his guard.

260. Slide Back or Peak Voltmeter. This instrument or method of using the tube is one in which the maximum voltage of an alternating or radio potential is matched or made equal to a D.C. potential and the D.C. potential is measured with an ordinary voltmeter.

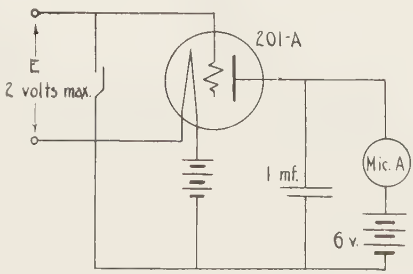


FIGURE 11.

Figure 9 is a diagram of the connections. A battery, C is placed in the grid circuit. With the terminals connected, the slide is adjusted to V_0 so that the current in the plate is zero. Then the terminals are connected to the points to be measured and the slide again adjusted for zero plate current. The difference of the two values of V gives the maximum voltage or amplitude of the voltage. This divided by 1.41 is the virtual voltage of the circuit, assuming the potential is that of a sine wave voltage. If the wave form is irregular, all we know is the maximum value of the potential.

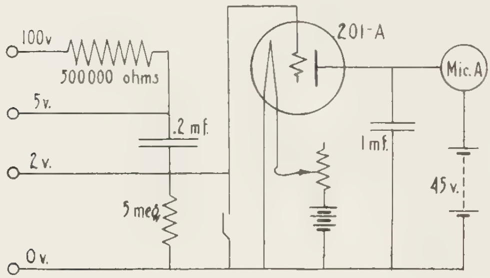


FIGURE 12.

261. Leaky Grid Voltmeter. The voltmeter diagrammed in Figure 10 is very simple to construct and is perhaps the most satisfactory for ordinary measurements. The following five rules or precautions are given. These must be applied in any case.

(1) The impressed voltage must cause no appreciable grid current.

(2) The filament terminal of the voltmeter must be grounded.

(3) The effective capacity and resistance must be known. (Especially necessary in measurement of small capacities.)

(4) The grid must not be isolated through high resistance. (Does not apply to leaky grid voltmeter.)

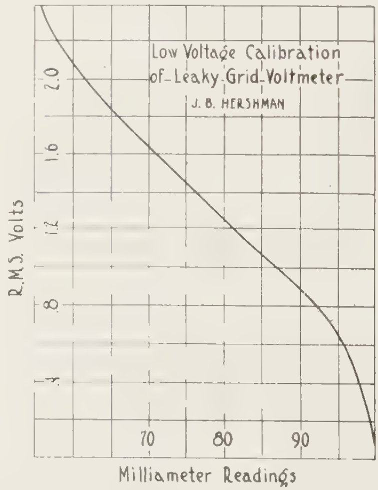


FIGURE 13.

(5) Inductive effects must be avoided by shielding and through the use of short leads.

The leaky grid voltmeter avoids excessive grid current through the use of a grid condenser and grid leak resistance.

The calibration curve of the leaky grid type is a reverse curve—the higher the potential the smaller the plate current. The voltage limit is reached when the plate current becomes zero. The voltage limit of this type using a 201A tube is about two volts.

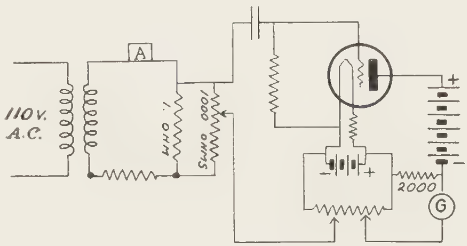


FIGURE 14.

262. Straight Detector Type. This type is diagrammed in Figure 11 and can be seen to be simply a tube connected for detection-plate current rectification. Figure 12 is a combination of Figures 10 and 11. When using the high potential terminal, care must be taken to see that all conditions are complied with.

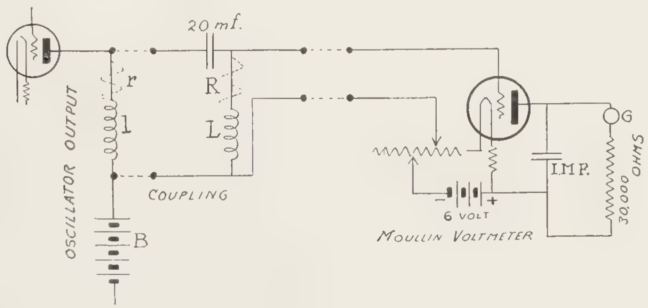
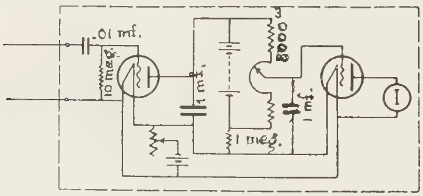


FIGURE 15.

A large resistance in series with the grid circuit gives the grid a negative potential and causes a decrease of plate current instead of an increase.

A good method is to have a current meter or thermo-junction in the circuit at some point in order to measure the current. If on making connections to the vacuum tube voltmeter the current

changes value the voltmeter is loading the circuit and the results are not the constants of the free circuit. Figure 13 is a calibration curve for a leaky grid voltmeter. Any vacuum tube voltmeter must be recalibrated from time to time since any change in the filament or other parts of the tube will change the readings. Figure 14 shows a calibrating circuit and a proposed type of vacuum tube voltmeter. Figure 15 shows a Moullin type voltmeter connected to measure the output potential of a power tube. Figure 16 shows a leaky grid type connected to an amplifying tube. This will measure very small values. Figure 17 is a General Radio Thermionic Voltmeter.



V.T. Voltmeter

FIGURE 16.

263. The Telephone as a Current Indicator. The ordinary head set has been used to estimate small alternating current of the order of a micro-ampere. This, of course, is with current of audio frequency. In conjunction with a rectifying crystal the telephone has been used to estimate radio frequency current. The principle of this is in reality the principle of one of the forms of vacuum tube voltmeter and has been discussed before. The calibration of a vacuum tube as a rectifier is much more certain than that of a crystal. With a crystal it is very easy to lose the sensitive spot and the calibration is lost. It is estimated that a good head set will respond audibly to a current of 1 micro ampere at a frequency near 1000 cycles.

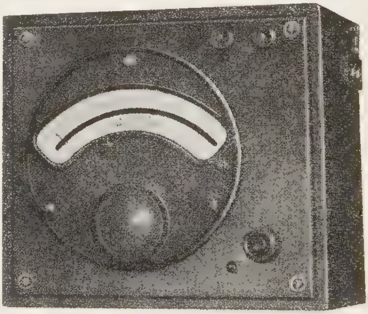
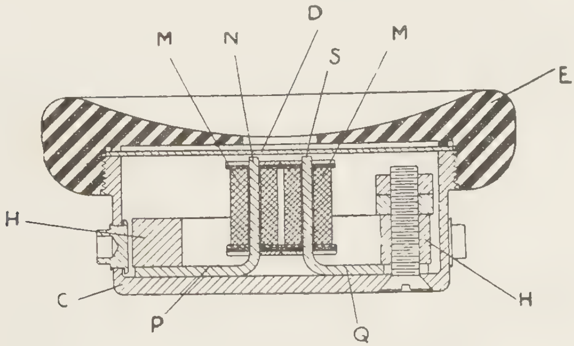


FIGURE 17.

264. Construction of Telephone. The telephone consists of a small horse-shoe magnet with short thin pole pieces so placed that the two poles can be connected by a thin steel disc. Around these two pole pieces are wound coils of fine copper wire No. 40 or

smaller. These two coils are connected in series so that the current in flowing either strengthens both poles or weakens both poles, depending on the direction of flow of the current. This horse-shoe magnet, with poles and windings, is placed in a brass or bakelite box. The edge of the box is high enough to support the thin steel disc a short distance from the pole pieces. Some head sets are adjustable so this distance can be varied. Over this a flat top or cap with a hole in the center is screwed. The varying current in the phones strengthens or weakens the magnet so that the disc is drawn closer or allowed to spring away. The fluctuations of this disc about its position of equilibrium produce rarefactions and condensations in the air which are carried to the ear and



Watch case telephone receiver.

FIGURE 18

are heard as sound. Figure 18 is a diagram of the watch case head set.

Head sets are usually rated by the resistance of the phone. The resistance is an easy way to indicate the number of turns of wire about the pole piece. The resistance of each coil varies from 500 ohms to 1000 ohms. There being two coils in each capsule and two capsules, one for each ear, the usual resistance of the head set varies from 2000 ohms to 4000 ohms. Although the resistance of the phones is used as a measure for the specification for the phone, resistance alone is not what is wanted. The number of turns is what is needed. A phone wound with high resistance wire would be of no use.

The mica disc phone is a phone which has a thin disc of mica instead of a steel disc. The center of the mica disc is cemented to a small rod which is actuated by a lever which is between the poles. The fluctuations of the lever causes the mica to vibrate. Figure 2, Chapter XXVIII shows a Baldwin mica disc head set.

For methods of estimating the current, see "Experimental Radio," Ex. 88.

265. Radio Frequency Resistance Standards. In general the resistance of a wire is greater for high frequency current than it is for a direct current. Tables have been calculated in which the size of a wire is given such that the R.C. resistance of the wire is not greater than the D.C. resistance by 1%. "Experimental Radio," p. 125. Bureau of Standards 47, p. 310.

Standard units of resistance can be prepared from small wire. In making these units the first thing is to decide the highest frequency at which the standard is to be used. For very high frequency the wire will be very fine and the current capacity will be small. These units may be all made to the same length by connecting the fine wire in series with a heavy copper wire or bar, the copper wire being so large that its resistance can be neglected. The ends of these units of resistance are soldered to convenient copper lugs or terminals which are amalgamated and arranged to dip into mercury cups. To protect the small wire the units are mounted and fastened in glass tubes with sealing wax, Figure 19. The distance between the mercury cups can be any convenient length such as 10 centimeters. By the cut-and-try method these units may be made to have a resistance of 1, 5, 10, etc. ohms, but for accurate work they must be measured and the exact values used so it is scarcely worth while trying to get values in even numbers of ohms.

FIGURE 19.

The diameter of the wire to be used depends on the kind of metal. Manganin wire has a very small temperature coefficient and a rather high specific resistance and makes good units. The current should not heat the wire very much. Even manganin

wire changes resistance at high temperatures. High temperature may change the resistance permanently by oxidation or other effects on the wire.

266. Radio Frequency Resistance Boxes. Convenient resistance standards can be purchased which are outwardly constructed like and can be used in the same manner as the ordinary resistance box. Figure 20 is a radio resistance box made by the General Radio Company.

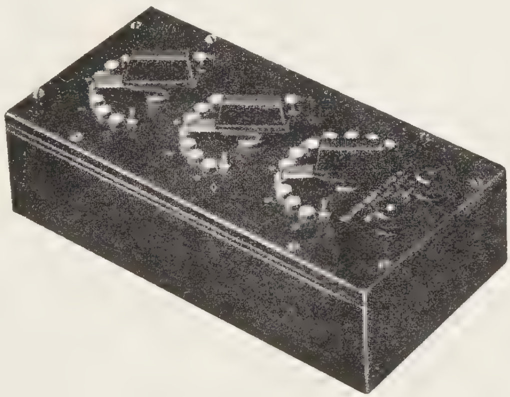


FIGURE 20

Figure 21 shows the method of winding the coils, two wires to be connected in parallel are wound on a thin mica or hard rubber strip which has been notched on the edges; the first wire is wound using every alternate notch; the second wire is wound in the reverse direction, using the notches that are left. As illustrated, the wires cross each other at the back. By this means the inductance is near zero and the capacity is kept low.

267. Wave Meters. In Chapter V "Introductory to Radio," we have spoken of the wave meter and said that the wave meter is the measuring device which is peculiar to radio. It can be used to measure wave length, frequency, capacity, inductance and decrement. It is often convenient to use it as an indicating device to indicate whether certain parts of the circuit are functioning or not. Figure 22 is a picture of Fleming's cymometer, an early type of wave meter. The theory of the wave meter has been given before, and we found that the value of the wave length, $\lambda = 1884\sqrt{LC}$ where L and C

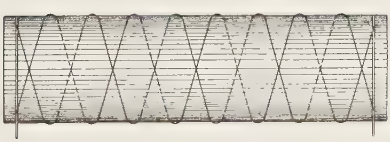


FIGURE 21.

are given in microhenries and microfarads respectively. Or $\lambda = 59.6\sqrt{LC}$ where L is given in centimeters and C is given in microfarads. Frequency can be calculated from $n = 1/(2\pi/\sqrt{LC})$. Or frequency can be calculated from $n = v/\lambda$.

Any coil and variable condenser can be used as a wave meter but for a good wave meter, good coils and good variable condensers must be used. Figure 23 shows some of the various methods of using wave meter circuits. For details of these circuits, see "Experimental Radio," page 41.

The coil should be wound on a good form—one made of good dielectric material—hard rubber, dry wood impregnated by boiling in transformer oil or paraffin. The form must have good

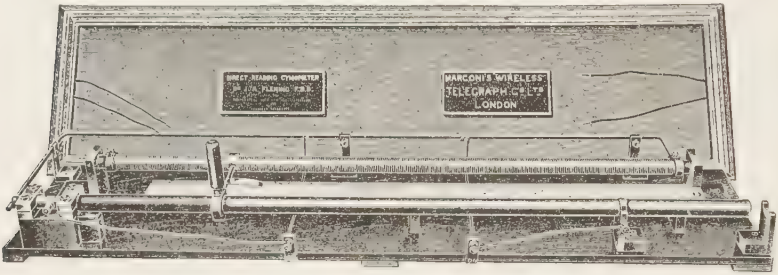


FIGURE 22. Fleming Direct-reading Cymometer. (Perspective view) 1905. The inductance is changed by a sliding contact on a long coil, the capacity is changed by sliding one cylinder of a cylindrical condenser. Fleming's Principles of Electric Wave Telegraphy.

dielectric properties and be of a material which will not change shape or dimensions with temperature or moisture.

The condenser must be one constructed in a manner such that there can be no change of capacity from time to time due to back lash or shaking of bearings. The bearings should be pivot bearings which are locked in position and supported by a rigid frame. The rotor should be well centered and so spaced that the rotor leaves are midway between the stator leaves or plates.

The coil and condenser should be connected together by short, strong connections. The relative position of coil and condenser and other parts must be rigidly fixed so they will always occupy the same relative position. The calibration may be in the form of a curve or a table may be furnished, giving the values at certain

positions. The curve is to be preferred. Some wave meters have the exact wave length or frequency given on the dial. This is con-

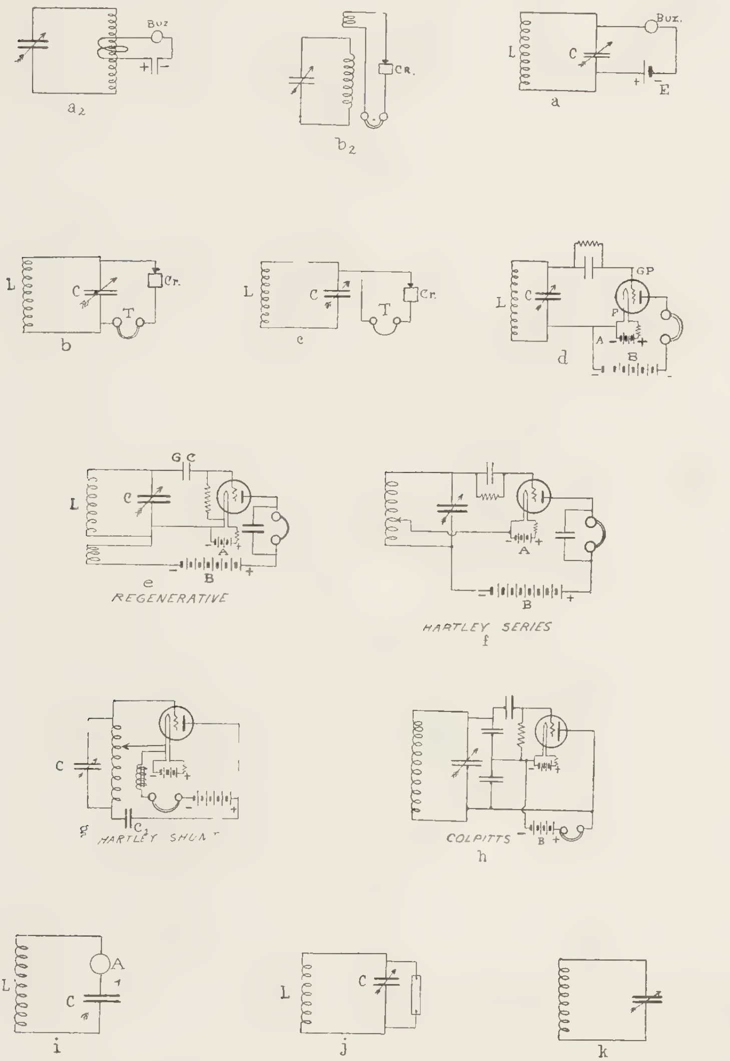


FIGURE 23.

venient in using the wave meter but is not accurate unless the greatest care has been exercised in placing the readings on the

the dial. In making some cheap wave meters one dial is calibrated and all other dials are made like this, assuming that all coils and all condensers will be exact duplicates of the first coil and condenser. If the coil or condenser should change in any way, the readings are not correct and the meter must be recalibrated and corrections applied to the dial readings.

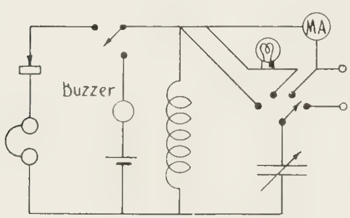


FIGURE 24.

The wave meter should be calibrated using the same indicating device with which it is to be used. The wave meter should not be calibrated using a buzzer if accurate readings are desired when used with a crystal and head set. The wave length depends to some extent on the accessories which are connected to the meter. Every wire or instrument has a certain amount of capacity and inductance.

It is often convenient to have a wave meter which can be used in various indicating devices, buzzer, head set, glow lamp, or milliammeter. This wave meter can be used with any of the connections and the readings taken from the same curve if extreme accuracy is not wanted. The standard wave meter should consist of a coil and a condenser and one indicating device.

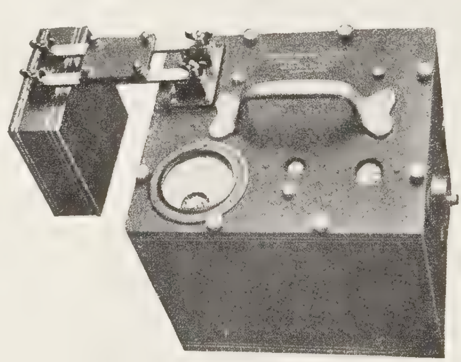


FIGURE 25.

Figure 24 is a diagram of connections of a wave meter having several indicating devices. It consists of a coil, a variable condenser and a four point switch by means of which the connections are made direct, Figure 23*k*, or

by closing the two point switch the connections are made for Figure *23a* or *23b*. The connections for Figure *23i* are made by connecting to the second point of the four point switch, i.e., to *A*, a flash lamp. The third point changes to a milliammeter in the same position, *A*, Figure *23i*. The two point switch is open for these connections. The fourth point changes to a connection so that a coil or resistance can be placed in series with the milliammeter so that resistance measurements can be made. Several coils can be used if the connections are made so they slip into binding posts or jacks.

If two or more coils are used, the calibration must be given as curves for each coil.

The wave meter can be made up into an oscillating wave meter, Figure *23f*. The position of the B and A batteries must be fixed in a case in order to keep the calibration constant. Change of filament current or B battery potential will cause small changes in the calibration. The oscillating wave meter is a great convenience when adjusting oscillating circuits.

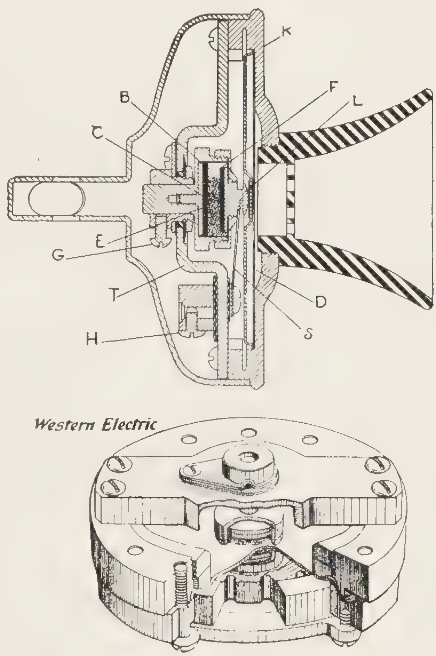


FIGURE 26. Diagram of single button carbon transmitter. Above. Diagram of double button transmitter. Below.

Figure 25 is a wave meter made by the General Radio Co.

268. Microphones. The microphone becomes a measuring instrument when response curves are made. The carbon microphone is well known and should need no explanation. It depends upon the fact that the resistance of carbon diminishes with pressure. The changing resistance of the carbon causes a fluctuating

current through the primary of the transformer. This fluctuating D.C. current causes an alternating current through the secondary of the transformer. This fluctuation is proportional to the intensity of the sound waves.

The double carbon button microphone consists of two carbon buttons which are connected in parallel in the local battery circuit. One of these buttons is on the front and the other is on the back of the diaphragm of the microphone. By this method the resistance of one button is increased, while the resistance of the other is diminished. This current is led through a transformer

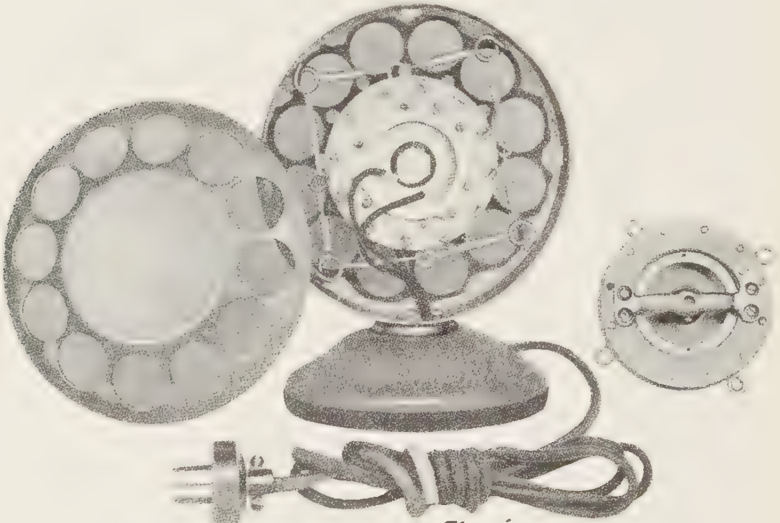


FIGURE 27. No. 387 Transmitter and No. 1-B Transmitter Mounting.

which has a mid tap on the primary coil. An increasing current flowing toward the mid tap in one-half of the coil causes an E.M.F. in the same direction as a diminishing current through the other half of the coil towards the mid tap.

Figure 26 shows a cross section of a single button microphone and of a double carbon button microphone.

Figure 27 shows a Western Electric carbon microphone used in broadcasting.

269. Condenser Microphone. The condenser microphone consists of a stretched diaphragm which is held a very short distance from

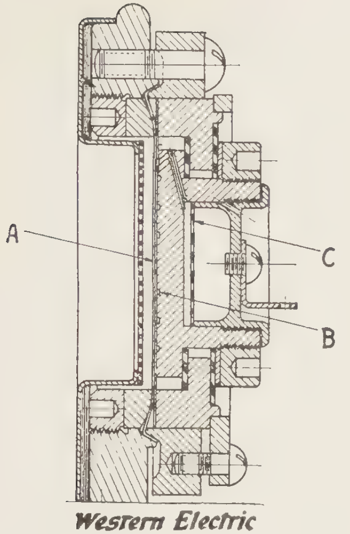


FIGURE 28. Sectional view of the electrostatic transmitter. A and B are the two plates of the condenser.

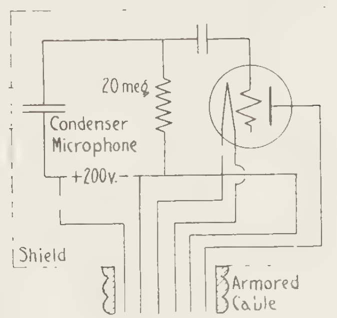


FIGURE 29.

a second plate, Figure 28. The capacity can be calculated from the formula, $C = KS/4\pi d$. The capacity changes due to the fact that the distance, d, is continually changing. A constant potential of about 200 volts is placed across this condenser. As the capacity, C, varies with the distance, d, the quantity of electricity changes in the condenser. This change of quantity is an alternating current which flows through the circuit. In this circuit there is a high resistance of about 20 megohms. The varying potential across this resistance is communicated to the grid of a tube through a coupling condenser as in any resistance amplifier. Figure 29 shows the connection of the first stage. The output of this condenser is so small that line noises tend to mask the effect. In order to overcome these line noises, it is necessary to house one stage of the amplifier in the same shielded housing with the microphone.

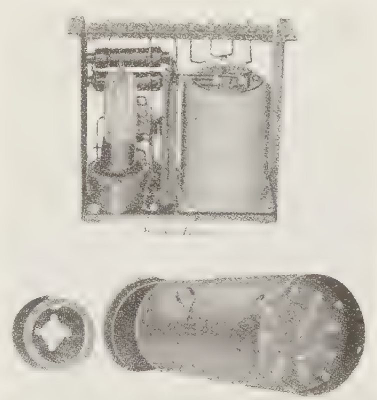


FIGURE 30. No. 47-A Condenser Transmitter Amplifier.

Figure 30 shows a microphone and also the amplifying unit which

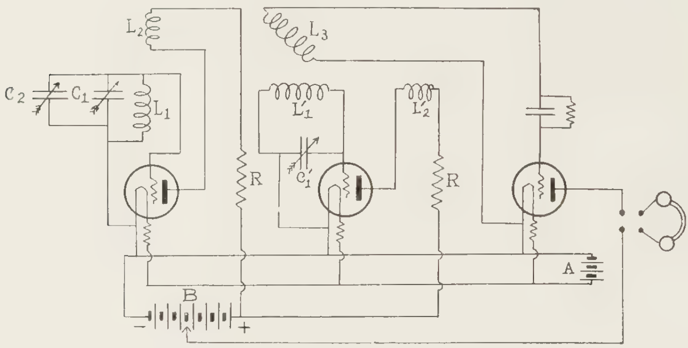


FIGURE 31. Diagram of the connections of the audio oscillator.

is associated with the microphone. Figure 24, Chapter XXIV shows a microphone as used in a broadcasting studio.

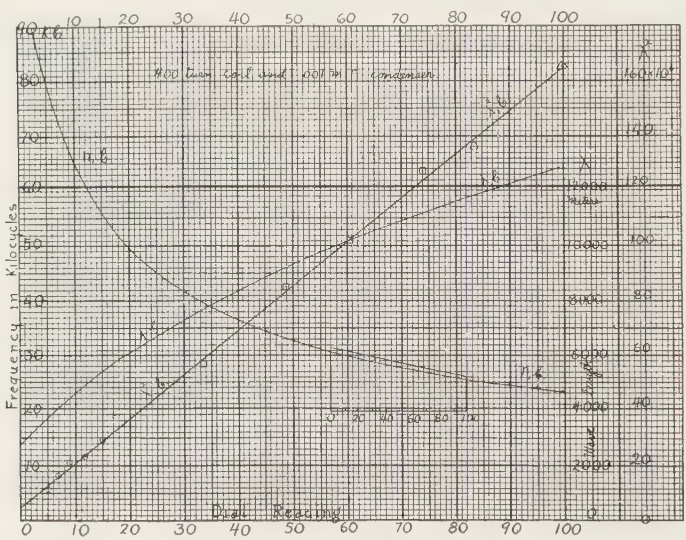


FIGURE 32. Calibration curves of the audio oscillator. The curve showing the frequency is approximately a straight line through a change of frequency of 5000 vibrations.

270. Beat Note Oscillator. If two radio frequency oscillators are brought close enough together a beat note is heard in a telephone

in either circuit. The pitch of this heterodyne note can be changed by changing the tuning of either circuit.

Figure 31 is a simple beat note oscillator made of honeycomb coils. If one of the oscillators is calibrated as a wave meter and a frequency curve is drawn, two points can be found such that the difference of frequency is 5000 or 10000 cycles when the capacity of either circuit is changed a definite amount. This capacity can be made the capacity of a small variable condenser in multiple with the first condenser. Figure 32 is a reproduction of such a curve. For details see "Experimental Radio," Experiment 109.

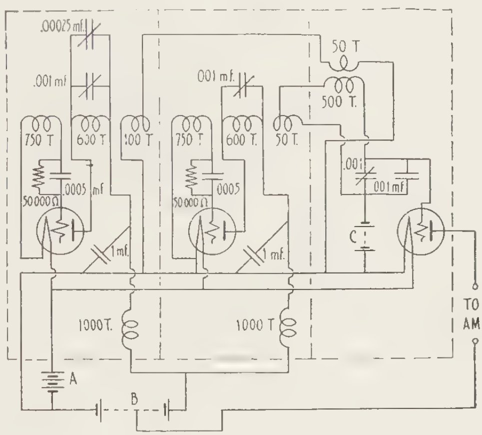


FIGURE 33.

Figure 33 is a diagram of a more complicated oscillator which, when the various parts are screened, gives a uniform output.

CHAPTER XX

RADIO RESISTANCE

271. Effect of Frequency. The resistance of a wire for high frequency current is larger than the resistance of the same wire for direct current. This is due to the fact that the inductance of a wire of small diameter is larger than that of a wire of large diameter. The resistance of a copper wire is inversely proportional to the cross section for direct current. If we have a wire of a certain diameter, one millimeter, say, the resistance for a given length is a certain amount. This will be the same as the resistance of a hollow pipe whose cross section is the same as that of the wire. Figure 1. If the inside diameter of the hollow pipe is 1 millimeter and the outside diameter is 1.41 millimeters, the conductivity of wire and pipe will be the same for direct current, since the cross sections are the same. The resistance of the pipe will be less than that of the wire for high frequency current.

FIGURE 1. Wire of 1 mm. diameter and a pipe 1.41 mm. diameter and a solid wire made up of the two.

Let us assume that the wire is slipped into the pipe, or that we have a solid wire in which the central portion can be removed.

If this wire of diameter of 1.41 millimeters is placed in a high frequency circuit, more current will flow through the pipe because the inductance of the pipe is less than that of the wire. Thus the current tends to flow on the shell or skin of the wire.

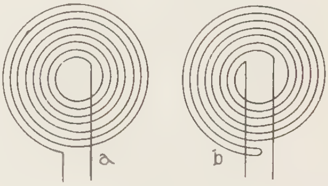


FIGURE 2.

This may be made more clear by imagining two coils of wire made up of equal lengths of wire of the same diameter but one wound in the ordinary fashion and the other wire doubled and wound so as to make a non-inductive coil. Figure 2. Since the two coils are made of the same wire identical in length and size, the

resistance of each coil is the same for direct current. Suppose each coil has a resistance of one ohm. If the two are placed in parallel the D.C. resistance will be $\frac{1}{2}$ ohm, and the heat developed will be proportional to $I^2R=I^2/2$. If 60 cycle A.C. current is used, most of the current will flow through the non-inductive coil and the heat developed in the coils will be greater than that for the D.C. current. The heat will be proportional to I^2 times one ohm, nearly. The resistance of the two in parallel will be greater than $\frac{1}{2}$ ohm. If the frequency is increased, most of the current will flow through the non-inductive coil, and for high frequency the impedance of the inductive coil will be so large that the current through it will be practically zero, and this coil can be removed without changing the total current. Thus the resistance of the two in parallel will be the resistance of the non-inductive coil.

If a solid wire is used for radio frequency, the inductance of the inner portion being greater than the outer portion, all the current flows through the outer portion and the inner portion can be removed without changing the resistance of the circuit. Since high frequency current flows mostly through the outer layers of the wire, the resistance of the wire for high frequency current is greater than the resistance of the same wire for D.C. current. In this connection it is well to remember that the energy dissipated in a wire (heat developed) is proportional to the resistance, and not proportional to the inductance. Inductance impedes the current but does not use up energy. In tuned radio circuits we annul the effect of inductances by means of capacity.

272. Calculation of A.C. Resistance. The formula for calculating radio resistance when the frequency is high is $R=R_0\sqrt{\pi n\mu a^2/\rho}$ where n is the frequency, μ is the permeability, a is the radius of the wire in centimeters, and ρ is the specific resistance of the material of the wire. This is for straight wire.

This is a rather complicated formula, but we see that the difference between the D.C. and A.C. resistance is greater the higher the frequency, the larger the diameter of the wire, the greater the permeability of the material of the wire, and the greater the conductivity of the metal. In large wires of copper the difference is great.

In small wires of German silver, manganin, advance, or nichrome, the difference is small. In iron and cromel wire the permeability tends to increase the difference.

The following table gives the frequency expressed in wave lengths and the diameter of the wires, such that the A.C. resistance differs from the D.C. resistance by 1%. Fifty-six hundredths (.56) of this diameter reduces the error to 0.1%.

Material	Conductivity in c.g.s. units.	Maximum diameter in millimeters						
		6000	1200	600	120	60	12	6 meters
Manganin	2.4×10^{-5}	2.4	1.1	.75	.34	.24	.11	.075
Iron								
$\mu = 1000$	10×10^{-5}	.033	.015	.010	.0046	.0033	.0015	.0010
$\mu = 100$	10×10^{-5}	.099	.044	.031	.014	.0099	.0044	.0031
Copper	57.5×10^{-5}	.49	.22	.15	.069	.049	.022	.015
Constantin	2×10^{-5}	2.6	1.2	.83	.37	.26	.12	.063
Platinum	10×10^{-5}	1.2	.57	.37	.17	.12	.057	.037
Carbon, arc	$.025 \times 10^{-5}$	23.6	10.6	7.5	3.4	2.36	1.06	.75
Concentrated $CuSo^4$	4.6×10^{-11}	175.	78.	55.	25.	17.5	7.8	5.5

For any kind of wire at any frequency, it is possible to get a wire small enough so that the D.C. resistance and the A.C. resistance does not differ by more than a certain small amount.

Radio frequency resistance boxes are made of wire whose diameter is small enough to make the A.C. resistance equal to the D.C. resistance. A radio frequency resistance box is correct for any frequency less than a certain specified frequency.

273. Comparison of A.C. and D.C. Resistances. The only experimental method of comparing A.C. and D.C. resistances is by means of heat methods. The differential thermometer method was first used by Fleming in comparing D.C. and A.C. resistance. The method is illustrated by the diagram, Figure 3. Two glass tubes exactly alike are formed into an *H* tube joined together by a *U* tube. The wires to be compared are two samples of wire exactly alike. They are placed one in each of the two tubes which are made air tight. A small amount of water is placed in the *U* tube to

serve as an index for pressure equilibrium. One of the wires is connected in a high frequency circuit and the other is connected into a D.C. circuit. When the currents are adjusted for thermal equilibrium as indicated by the water in the U tube, then $I^2R=i^2r$, and if the capital letters represent the high frequency resistance and current, then the A.C. resistance, $R=i^2r/I^2$.

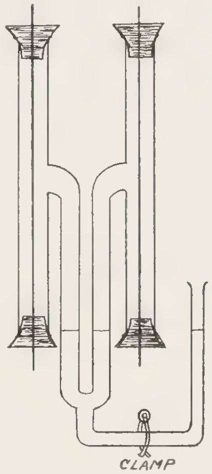


FIGURE 3.

When wire is wound up into a coil the high frequency resistance is generally greater than that for the wire when it is straight. Formulae can be found which will give the resistance, but as a general thing they are very complicated.

274. Application. In the first part of this chapter it was shown that the current tends to flow on the surface of the wire. This has led to some misconceptions, one of which is that the greater the surface the less the resistance. Small wires have been bundled together into a cable supposing that because the total surface of the wires is greater than that of a single wire of the same combined cross section, the resistance is less. The fact that the surface must be outside surface has been forgotten. The resistance of a cable made of fine uninsulated wires is greater than a solid wire. As a general thing the strands are woven so that the wire is now on the outside and again in the inside. The current tends to flow on the outside of the cable so the current flows across from one wire to the next in order to remain on the outside, and the resistance to its flowing is greater than in a solid wire, due to the resistance of the points of contact through which the current flows.

If the wires are stranded together and are perfectly insulated, one from another, then the current in each single strand is the same, and the entire cross section is used, then the resistance is lessened. The resistance is less, but the inductance is greater than that of a solid wire. If through age or weathering the insulation between wires breaks down, then the resistance is increased and the stranded wire is worse than solid wire and may be even worse

than a bundle of bare wires. If one wishes to make a general statement which will apply to the usual run of conditions, it may be said that some of the stranded wire is about as good as solid wire.

275. Methods of Measuring Radio Resistances. There are two methods of measuring resistance at radio frequency, the resistance variation method and the impedance variation method. In the resistance variation method a radio frequency ammeter, and a radio frequency resistance box or unit is placed in a radio circuit which is inductively coupled to an oscillating circuit. The circuit is tuned until the ammeter reads the maximum current. Resistance is inserted into the circuit and the current is read again. In practice the circuit will need to be tuned again until the meter reads a maximum. The resistance should be so constructed and placed that the circuit tuning will be changed as little as possible by the insertion of the resistance. Since the circuit is tuned, $I_1 = E/R_0$ in the first case, where R_0 is the resistance of the circuit and I_1 and E are current and E.M.F. in the circuit. When resistance, R, is inserted, $I_2 = E/(R_0 + R)$. From these two equations we get $R_0 = RI_2/(I_1 - I_2)$. A particular case is when I_2 is made equal to $\frac{1}{2}$ of I_1, then $R_0 = R$. R_0 is the resistance of the coil, condenser, ammeter and any other resistance in the circuit. The ammeter is usually a milliammeter in which the heater wire is so small that the high frequency resistance is the same as the D.C. resistance, and its resistance can be determined by the usual D.C. methods. The ammeter resistance may change appreciably with temperature (with current). The resistance of the condenser, if a good radio frequency air condenser, is small and can usually be neglected.

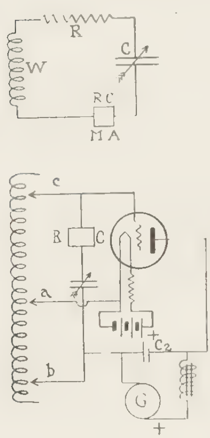


FIGURE 4.

The diagram, Figure 4 shows the connections of the circuit being measured and of the oscillator. The coupling of the circuits should be so loose that the variation of the resistance in the circuit does not change the current in the oscillator.

276. Measurement of the Resistance of the Oscillator. Resistance may be inserted in the oscillator circuit and the resistance of the oscillator measured in the same manner, Figure 4. However, in

certain cases the E.M.F. will change due to the extra resistance, and the results will not be correct. Sometimes the measured resistance as calculated is less than the ammeter resistance.

277. Impedance Variation Method. In the impedance variation method the circuits are the same as in the resistance variation method except that no standard of resistance is used. In this case instead of using the current, the square of the current is used. The circuit is tuned for resonance, the square of the current is read and the capacity of the condenser is read.

The capacity of the condenser is changed a convenient amount and the square of the current read again.

In the first case $E^2=I^2(R^2+(L\omega-1/C\omega)^2)=I^2R^2$ since the circuit is in resonance with the oscillator. In this case $L\omega=1/C_r\omega$.

In the second case $E^2=I_2^2(R^2+(1/C_r\omega-1/C\omega))^2$. Solving for R, from the two equations we get,

$$R=[(1/\omega)(C_r-C)/CC_r]\sqrt{(I_1^2)/(I_1^2-I_2^2)}.$$

If I_2^2 is made equal to $\frac{1}{2}$ of I_1^2, then

$$R=1/\omega(C_r-C)/CC_r.$$

A radio frequency galvanometer is convenient in this method since the readings are proportional to the square of the current. The capacity of the condenser should be high, since it is assumed that all the capacity of the circuit is in the condenser.

278. Substitution Method. If in Figure 4 the unknown resistance is placed in the position, R, in the wave meter circuit and the wave meter circuit is tuned for maximum current and then the unknown is replaced by a radio frequency box and the resistance is adjusted so that the maximum current is the same as the maximum current was when the unknown resistance was in the circuit, then the resistance in the box is equal to the resistance of the unknown.

The unknown resistance should have no or little inductance. If the unknown is a coil, the readings of the condenser will be so much different in the two cases there may be a question of the other resistance in the circuit being the same in the two cases.

The accuracy of the measurement of radio frequency resistance is not anything like the accuracy obtained with ordinary resistance measurements. It is necessary to use certain precautions. The resistance of a wire or other apparatus depends upon its position with respect to other objects. Instead of regular radio frequency

resistance boxes, resistance units can be used. A resistance may be prepared of a straight piece of high resistance wire and the change may be made by inserting this in place of a bar made of high conductivity material. One curious fact may be noted when the frequency is high. This is that the resistance of the standard and the bar in parallel is greater than the resistance of the bar.

279. Resistance of Radio Frequency Coils. The resistance of a wire depends not only on size of the material and frequency; it also depends upon its position with respect to other objects. It is well to remember that in measuring radio frequency resistance we are measuring the energy losses in the coil. Anything which absorbs energy from the circuit will increase the resistance of the circuit. All heat losses appear as resistance. Thus dielectric losses, eddy current losses and radiation losses appear as resistance.

In a coil the distribution of the current in the wire is different from that when the wire is straight, and there may be, and usually are, losses in the insulation and forms on which the coil is wound. Self-supporting coils such as "spider web" coils or Lorentz coils, do not need tubes or forms, but the length of wire used in the construction is increased. Experiment shows that for the broadcast range single layer coils made of wire about size No. 18 wound on good forms have minimum resistance.

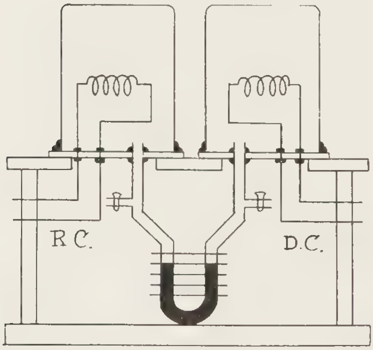


FIGURE 5. Drawing showing the differential thermometer. The heat developed in the coil in the left hand beaker by the radio frequency current is balanced by the heat developed in the coil in the right hand beaker by the direct current. The equality of the height of the water in the U-tube indicates when equilibrium is established.

A good coil may be wound and have its resistance increased by placing it in the set close to other objects. Toroid coils tend to concentrate the field to the space inside the coil, but the resistance is higher than that of a single layer coil. For sharp tuning a coil of low resistance and low capacity is needed. Figure 5 shows the method of measuring coils by the thermal method.

280. Condenser Resistance. The resistance of a condenser consists of the resistance of the connecting terminals of the condenser and the hysteresis losses in the dielectric. It is well known that Leyden jars get hot when connected to an alternating circuit. This heating is due to the dielectric loss in the glass. Any heating of a condenser due to any cause will appear as a resistance when resistances are measured. These various losses may be represented as a resistance in series and as

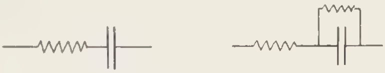


Figure 6. At left, diagram showing a perfect condenser in series with a resistance; at right, showing how the actual resistance of a condenser may be in series or in parallel with a condenser.

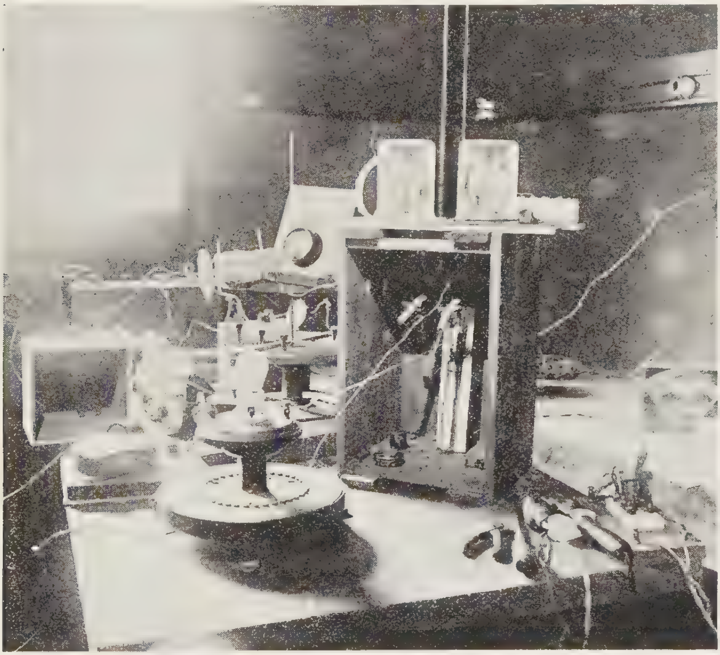


Figure 7.

resistance in parallel with the condenser. When we speak of the resistance of a condenser as being a certain number of ohms, we mean the equivalent series resistance. The condenser is equivalent

to a perfect condenser of the same capacity as the given condenser and a resistance of the same number of ohms placed in series with the perfect condenser. Figure 6.

The only method of making absolute determinations of the resistance of a condenser is by means of the thermal method. Figure 7 is a photograph of the apparatus used by the author in determining the resistance of condensers. A good variable condenser has a resistance of about .1 ohm at a frequency of 1,000,000 cycles per second. This is usually small compared to other resistances in the circuit and can be neglected.

The usual method of measuring the resistance of a condenser is to measure the resistance of a circuit in which a good air condenser is inserted and assume that the resistance of the air condenser is zero. The condenser to be measured is substituted for the air condenser, the resistance of the circuit is measured again and the difference of the two measurements is assumed to be the resistance of the condenser.

At low frequencies the resistance of a condenser can be measured by means of the three voltmeter method. See Chapter IV on Alternating Current.

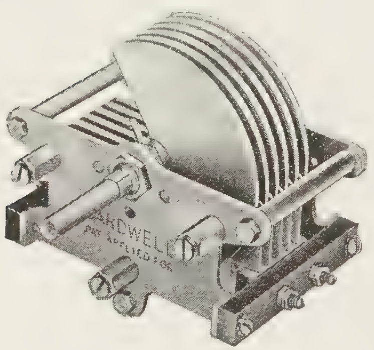


FIGURE 8.

From the vector diagram the resistance of the condenser can be determined. The phase angle is nearly 90 degrees. The amount the angle lacks of being exactly 90 degrees is proportional to the resistance of the condenser. This small angle is called the phase difference. It is usual to speak of the phase difference instead of the resistance when speaking of large condensers at low frequency. Dielectric losses diminish as the frequency is increased. The dielectric loss of a good air condenser is relatively small at low frequencies and calculations made from the rate of variation at low frequencies show that the losses at high frequencies are almost zero. This does not take into account eddy current losses or other losses which increase

with frequency. Since heat measurements show that a good air condenser of the "low loss" type has resistance of the order of .1 ohm the substitution method of condenser resistance measurement can be used. Use a good "low loss" condenser and assume the standard to have zero resistance. Figure 8 is a tapered plate low loss condenser.

As has been stated before, the resistance of a radio condenser consists of series resistance, resistance of the terminals, and resistance of the plates to the current which flows through the plates as the current is distributed in the plates. There are also eddy current losses. These resistances may be said to be metallic resistances, and these resistances increase with frequency. Dielectric losses diminish with frequency. The manner of variation in any individual condenser will depend upon the relative amount of metallic resistance to the dielectric resistance.

In a variable condenser the resistance increases as the capacity of the condenser diminishes. This can be explained because the potential across the plates increases as the capacity diminishes, according to the equation $Pd=I/C\omega$. This increased potential across the plates will increase the dielectric losses or shunt losses. As the capacity is diminished the area of the plates are diminished, thus making the cross section of the conductor less.

Mr. B. D. Morris (Phys. Rev. 33, p. 1076, 1929) has found that the following equation $R_s=R(300/\lambda)(C/.001)^{3/2}$ applies to most condensers. Where R_s is the resistance of the condenser under standard conditions, i.e. 300 meters wave length and capacity .001 microfarads, R is the resistance of the condenser at wave length, λ, when set at the capacity, C. When this equation is applied to the published data, the values of R_s for any set of observations may vary as much as 300%, but the resistances were of the same order. Results obtained by the heat method gave results ranging from .002 ohms to about .01 ohm. When this equation is applied to results made by the substitution method where a condenser of known resistance is substituted, the results are practically the same as the above. Applying this formula to the results made by the resistance variation method where the resistance of the coil is calculated or eliminated, the results are much larger. The values of R_s ranged from a quarter ohm to 1.3 ohms.

Miss Fletcher has found that if in the above formula the square root of the ratio of the wave lengths is used instead of the first power, the results for R_s are much more constant when applied to two certain condensers with aluminum plates, while Morris' formula applied to a certain brass plate condenser.

Since the resistance of a condenser consists of metallic resistance and dielectric resistance, and the relative amounts of each differ with any particular condenser, it can not be expected that any one formula will apply to all condensers. However, the application of these formulas indicate that one can not judge a condenser because some few results give values which are very low. If one sets the condenser to maximum capacity and uses a small coil so the wave length is very low, the result will be very low. The actual resistance of this condenser may be much greater than one set for low capacity and long wave length, where the resistance may be several ohms.

The application of the formula brings out the fact that the resistance variation methods in which the coil resistance is calculated or eliminated measures something more than the heat generated in the condenser. This has been explained by saying the difference is radiation resistance, but calculation shows that the radiation is much too low to account for the discrepancy.

281. Effect of Resistance. In the equation,

$$I = \frac{E}{\sqrt{R^2 + (L\omega - 1/C\omega)^2}}$$

the current, I, is a maximum when the circuit is tuned. The maximum current is $I = E/R$. Thus if the resistance is large the maximum current is small. Not only is the current small but the variation of the current with the tuning is small when the resistance is large. If the resistance is very large the current depends upon the value of the resistance and very little on the term involving the capacity and inductance. Exact tuning makes little or no appreciable difference. Resistance makes a receiving set inefficient and unsatisfactory. If a resonance curve is made of a circuit the peak of the curve is found to be very low and flat. A resonance curve, Figure 19, Chapter XV, is one in which the radio frequency current is plotted as ordinate, and wave length, frequency, capacity, or dial setting of the tuning condenser

is plotted as abscissa. If the resistance is small the curve has a very high peak. In the first place the tuning is said to be broad and in the last case the tuning is said to be sharp.

In a transmitter high resistance cuts the efficiency of the radio frequency generator and makes the frequency more or less variable.

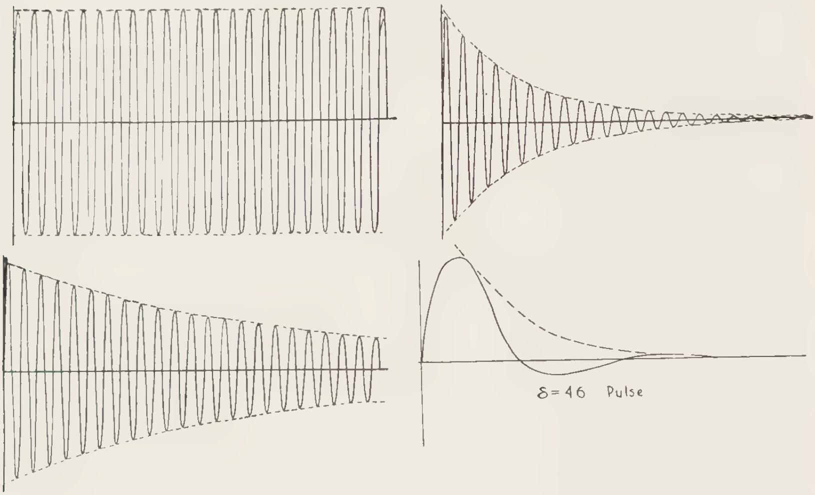
282. Decrement. Decrement, or more strictly, logarithmic decrement, is a term which is used in radio as a measure of the sharpness of tuning. The term originated in the early days with damped wave transmission. In damped waves the amplitude gradually diminishes in the same manner as any harmonic motion dies out. Decrement means the same as the term logarithmic decrement when applied to a ballistic galvanometer. The decrement is the logarithm of the ratio of one amplitude to the next amplitude. The equation for current in a circuit containing resistance, capacity and inductance, is $I = I_0 e^{-Rt/2L} \sin \omega t$. $RT/2L$ is the decrement of the circuit. Thus the decrement is proportional to the resistance of the circuit. In a certain sense, decrement is a measure of the resistance of the circuit.

In Chapter XV, on coupling, we saw that close coupling had the effect of making the circuit resonate at two frequencies. If a resonance curve is taken in such a case we have a curve like that in Figure 18, Chapter XV. This rendered the resonance curve broad so the term decrement is applied to this type of curve from a coupled circuit as well as to a simple tuned circuit. In the theoretical discussion of decrement we find that the decrement depends on the resistance of the circuit, while in practice it depends on the coupling of the circuit, as well as on the resistance. Figure 9 shows waves of various decrement, also a continuous wave or one in which the decrement is zero.

If we have a wave like the last, in Figure 9, in which the decrement is so large that the second amplitude is nearly zero, we have what might be called a pulse. This pulse might be likened to a blow from a hammer. If we have a boy in a swing, he can swing in two ways. Perhaps he can have his father give him a big push in the morning as he goes to work and another push at noon and another push at night. The boy swings high for a short time and then the "cat dies," and there is a long interval in which he does not swing. If the decrement is not large, the swing does not come to rest so soon. The more friction the faster the swing comes

to rest. If the decrement is made zero there must be someone pushing all the time or there must be no friction. The case of absolutely no friction, or resistance, is impossible. In continuous wave circuits, energy is fed in all the time at a regular rate, giving waves of constant amplitude or zero decrement.

If we have a transmitter which has a large decrement so that the wave transmitted is a pulse, it does not make much difference about the tuning of the receiver. Since the pulse has no frequency all receivers will be affected alike, independent of frequency. A hammer blow will start any pendulum to vibrating, independent of length of the pendulum.



I Continuous wave, $d=0$ III $d=.2$
II $d=.06$ IV $d=4.6$ Pulse

FIGURE 9.

The more vibrations before the wave dies out, the easier it is to tune the station out of the receiver. If the first pulse affects the receiver, the pulses or vibrations which follow will soon be in the direction to retard the effect of the first pulse unless the natural frequency of the receiver is that of the wave. Thus the more waves in a wave train the less the decrement and the sharper the tuning. A spark station whose decrement was greater than .2 was outlawed by the U. S. authorities. When the decrement is

.2 there are 23 vibrations or waves before the amplitude falls to 1% of the initial amplitude. Thus a spark station must make 23 or more vibrations before the waves die. There must be at least 23 waves for each spark.

To liken radiation from a radio station to the radiation from a light source: a station with a low decrement gives a line spectrum of a definite wave length, while a large decrement means a band spectrum covering a large range of wave lengths. It is hard, or next to impossible to tune out a station with a large decrement. Another advantage of small decrement is that all the radiated energy of the sending station is concentrated on one wave length, while the energy is scattered over a broad band when the decrement is large.

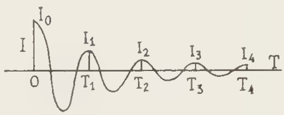


FIGURE 10.

283. Derivation of Equation. The solution of the differential equation of an oscillating circuit containing resistance, inductance, and capacity may be put into the form $I=I_0e^{\ \sigma t}$ $\sin \omega t$, where I_0 is the initial or maximum value of the current, I is the value of the current at any time, t; ω is the angular velocity, or $2\pi n$, n being the frequency and $\alpha=R/2L$, R being the resistance and$L$ the inductance of the circuit.

The equation can be represented by the curve of Figure 10.

The amplitudes are

$$I_0=I_0e^{-\alpha 0T}$$

$$I_1=I_0e^{-\alpha T} \quad \text{and}$$

$$I_2=I_0e^{-2\alpha T}$$

etc.

$$\frac{I_1}{I_2}=\frac{I_0e^{-\alpha T}}{I_0e^{\ \alpha 2T}}=e^{\alpha T}$$

$$\frac{I_2}{I_3}=\frac{I_0e^{-\alpha 2T}}{I_0e^{-\alpha 3T}}=e^{\alpha T}$$

$$\frac{I_n}{I_{(n+1)}}=e^{\alpha T}.$$

From this

$$\alpha T=\log\frac{I_1}{I_2}=\log\frac{I_2}{I_3}=\log\frac{I_n}{I_{(n+1)}}$$

This is the same as the usual logarithmic decrement used in ballistic galvanometer work, except in ballistic galvanometer

work we follow the English fashion of taking the ratio of the two successive swings in the opposite direction instead of the two successive swings in the same direction. Thus the decrement in U.S. wireless is two times the value determined by the English method. The determination of I_1, I_2, etc., or successive amplitudes of the current is impossible where the frequency is in the order of 1 million, as it is in wireless work.

In the above equation the frequency

$$n=\frac{1}{2\pi}\sqrt{\frac{1}{LC}-\frac{R^2}{4L^2}}.$$

If R is small or zero, this becomes $n=(1/2\pi\sqrt{LC})$. This is the same for n, obtained from the equation of alternating current in a circuit containing resistance, inductance and capacity, with an alternating E.M.F.

$$I=\frac{E}{\sqrt{R^2+(L\omega-1/C\omega)^2}}.$$

The value of I is a maximum when $1/C\omega-L\omega=0$, i.e., $I=E/R$. If $L\omega=1/C\omega$, then $(2\pi n)^2=1/CL$ or $n=(1/2\pi\sqrt{LC})$. The above equation for I can be written

$$I^2=\frac{E^2}{R^2+(L\omega-1/C\omega)^2}.$$

When the reactance term $L\omega-1/C\omega=0$, the circuit is in resonance with the E.M.F. Then

$$I_r^2=\frac{E^2}{R^2+(L\omega-1/C\omega)^2}=\frac{E^2}{R^2}$$

where C_r is the value of the capacity which makes the circuit in resonance with the E.M.F. Then $L\omega=1/C_r\omega$.

If the capacity is changed until $I^2=\frac{1}{2}I_r^2$, I_r^2 being the resonance value, then

$$\frac{1}{2}I_r=\frac{E^2}{R^2+(1/C\omega-1/C_r\omega)^2}$$

since doubling the denominator will halve the value of I^2. Then

$$R^2=1/\omega^2([C_r-C]CC_r)^2 \text{ or } R=1/\omega(C_r-C/CC_r)$$

$$T=1/n=2\pi/\omega \text{ and decrement } d=\alpha T=RT/2L$$

$$d=\frac{RT}{2L}=\frac{1}{\omega}\left(\frac{C_r-C}{CC_r}\right)\frac{2\pi}{\omega 2L}=\pi\left(\frac{C_r-C}{C_r}\right)\frac{1}{\omega^2}\frac{2}{2CL}$$

$$d=\pi\left(\frac{C_r-C}{C_r}\right)$$

where C_r is the value of the capacity at resonance and C is the value of capacity which reduces the mean square of the current to $\frac{1}{2}$ its value. In this manner the decrement is measured by determining the resistance in terms of a capacity.

The decremeter consists of a coil, a variable condenser, and a radio frequency milliammeter or galvanometer connected in series and placed near the radiating source. The decremeter is simply a wave meter which has a milliammeter in the circuit. The capacity is varied until the current is a maximum or the circuit is in resonance with the source. The capacity of the variable condenser is then varied until the mean square of the current is reduced to $\frac{1}{2}$ the first value. Then the decrement is calculated. This gives the sum of decrement of the source, aerial, and the decrement of the decremeter. This is exactly the same as in measuring the resistance of a 1 to 1 transformer circuit by introducing resistance in the circuit until the current is made $\frac{1}{2}$. The value of R introduced is equal to the sum of the resistances in the two circuits. This holds if the mutual inductance is large as in a transformer.

Since $d=\alpha T=(R/2L)T$, doubling the resistance in either circuit will double the decrement of either circuit.

Thus the introduction of resistance in the decremeter circuit until the current in the decremeter is made one half, the circuit being kept in resonance all the time, will double the decrement of the decremeter. If $D_1=d_1+d=$first decrement measurement and $D_2=2d_1+d=$second decrement measurement with resistance inserted in decremeter circuit, then $d_1=D_2-D_1$.

The decremeter is assumed to be loosely coupled to the aerial so as not to affect the aerial circuit.

An accurate method of getting the decrement of a decremeter is to use a continuous wave current such as is generated in the modern tube circuits or radio telephone circuits. In these circuits the wave is continuous, the decrement is assumed to be zero and the decrement measured is that of the decremeter alone.

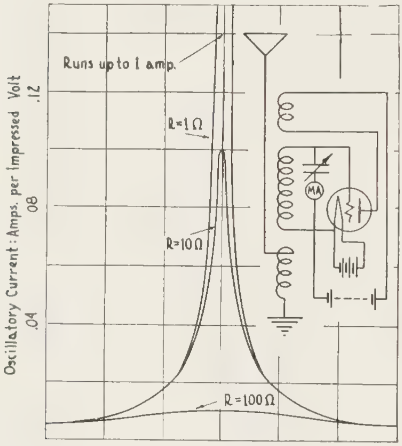


FIGURE 11.

Thus we can define the decrement in terms of the amplitudes or by the way the current dies down, or theoretically we can define it in terms of the equation $d=(R/2L)T$. Defined by the amplitude, a C.W. station has no decrement and was so assumed during the days of the spark stations. But C.W. stations have resistance and inductance, since $d=(R/2L)T$ and $T=\pi 2\sqrt{LC}$, $d=\pi R\sqrt{C/L}$.

Thus the decrement can be considered to be a constant of a simple radio circuit, being π times the product of the resistance by the square root of the ratio of the capacity to the inductance of the circuit.

284. Negative Resistance. In the paragraph on the conditions for oscillations, Chapter XIV, we had the equation $I=I_0e^{\alpha t}\sin\omega t$ and found that

$$\alpha=-\frac{CR-BL-GM}{2CL}=-\left[\frac{R}{2L}-\left(\frac{GM-BL}{2CL}\right)\right].$$

Thus if $(GM-BL)/C=R$ then $\alpha=0$.

If in Figure 11 the circuit LCR has a resistance of 100 ohms and an E.M.F. is induced into it from the aerial, the current will be the values shown in the resonance curve marked 100 ohms. If the tube is coupled as in the figure so as to be regenerative, and a resonance curve like that marked 10 ohms is obtained, then the

total resistance must be reduced or the value of $(GM-BL)/C$ must be 90 ohms. Therefore, due to the regeneration, the tube seems to have a negative resistance.

The resonance curves when the regeneration is introduced are much more sharp than before the regeneration. The selectivity of the circuit is much increased and the decrement of the circuit is diminished.

CHAPTER XXI

SPARK TRANSMISSION

285. Historical. Spark transmission or damped wave transmission was the first method used in radio. This method depends upon the fact that the discharge of a condenser through an inductance is oscillatory. The oscillatory discharge of a Leyden jar is the expression used to describe this phenomenon. This is the method originally used by Marconi and was the method of transmission in common use until about 1920 or 1922.

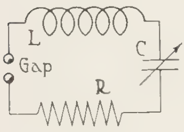


FIGURE 1.

286. Charge and Discharge of a Condenser through an Inductance. In a circuit containing a condenser, inductance and resistance, as in Figure 1 the equation for discharge is

$$Ldi/dt+Ri+dq/C=0$$

or

$$Ldi/dt+Ri+1/C\int idt=0$$

which becomes

$$Ld^2i/dt^2+Rdi/dt+1/Ci=0.$$

For charge we have the same equation except the equation is equal to E, instead of zero.

When the resistance is small the solution of both of these equations can be put into the form

$$I=I_0E^{-\alpha t}\sin\omega t.$$

Where I is the current at time, t; I_0 is the current at the time $t=0$; $\alpha=R/2L$, and $\omega=2\pi n$. The frequency,

$$n=\frac{1}{2\pi}\sqrt{\frac{1}{LC}-\frac{R^2}{4L}}.$$

When the resistance, R, can be considered to be small or zero compared with $4L$, then $n=(1/2\pi\sqrt{LC})$. This value of the frequency is the same as that obtained when we have undamped oscillations from a high frequency generator such as a tube generator. See Chapter XIV.

This current can be represented by a sine curve in which the amplitude gradually diminishes exponentially. Figure 8, Chapter XX, is such a form. A curve of this kind is known as a damped sine wave.

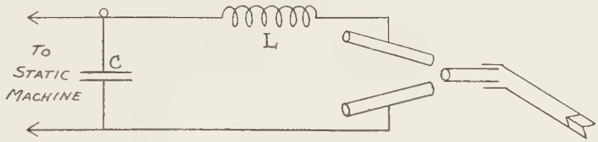


FIGURE 2.

287. *Methods of Showing the Oscillations.* Professor Henry, of Princeton University in 1840, proved that the discharge of a Leyden jar is oscillatory. The oscillations can be shown by discharging the circuit through an oscillograph. The common method

FIGURE 3.

is to include an open spark gap in the circuit and to observe the spark by looking at the image of the spark in a rotating mirror. The rotating mirror stretches the spark out in the horizontal direction.

A better method is to include in the circuit a spark gap made of two small rods placed so as to make an open V, the rods being not quite parallel. The ends of the rods should be about five millimeters apart. Against the small end of the V, direct an air blast from a small tube. The set-up is illustrated in Figure 2. The initial discharge takes place across the shortest path. The air is ionized and driven toward the wider portion of the V. The subsequent oscillations take place through the path of least resistance, or through the ionized air. Figure 3 is a photograph of a spark taken by that method.

288. Frequency of Spark and Frequency of Oscillation Different. It may be well to call attention to the fact that the frequency of the oscillation is not the frequency of the spark. The frequency is the frequency of the circuit which depends upon the value of the capacity of the condenser and the inductance of the coil. The frequency is of the order of one or ten hundred thousand per second. The frequency is, as a general thing, above the audible frequency of the human ear. Each spark in the spark gap gives a "bunch" of perhaps one hundred waves at the frequency of perhaps a million per second. If there are one hundred sparks per second, the circuit oscillates during one ten thouandth of a second and then is quiet for 99/10000 of a second waiting for the next spark. The circuit is then actually oscillating during 1% of the time. This is illustrated in Figure 4. Of course, it is impossible to represent the relative intervals in true proportion in the figure.

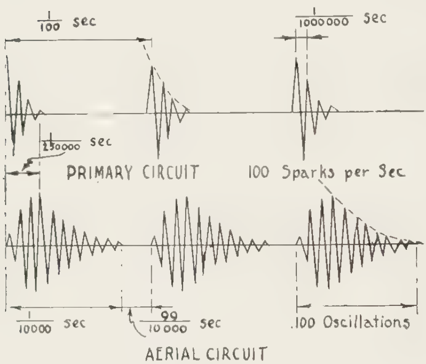


FIGURE 4.

289. Early Transmitters. The original method of using damped wave transmission was to insert a spark gap in the down lead of the aerial, Figure 5, the capacity of the circuit being the capacity of the aerial and the inductance of the circuit being the inductance of the down lead plus the inductance of the "loading" coil, if any. The spark gap was connected to a Ruhmkorff coil, or to a high potential transformer.

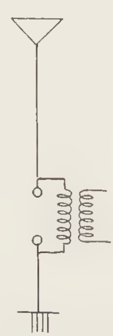


FIGURE 5.

290. Damping Proportional to Resistance. In the equation, $I = I_0 e^{-\alpha t} \sin \omega t$, α is the damping coefficient. The greater α, the faster the current dies down to zero. Remembering that $\alpha = R/2L$, we see that the greater the resistance, R, in the circuit the faster the current dies down. In the aerial circuit the resistance is the resistance of

the aerial, the ground, and the resistance of the spark gap. The spark gap resistance is always large and the damping factor is very great. The oscillations in the circuit are very much like the curve in the Figure 9*d*, Chapter XX. The oscillations consist principally of the first oscillation. If any energy is to be transmitted, most of it must be in the first oscillation.

291. Pendulum Analogy. If we wish to make a pendulum vibrate, we might do it in one of two ways. We might tap it lightly with a lead pencil, timing the taps to the natural frequency of the pendulum, or we might hit it a sharp blow with a hammer. A second pendulum of different length would respond feebly to the taps of the lead pencil if they were applied with the original frequency, while the sledge hammer blow would cause the same effect in both pendulums.

If most of the energy which is transmitted by the ether is in the first oscillation of the transmitter and in the first wave of the ether, all aerials are disturbed about the same. If the large decrement transmitting station can be received by the receiving station there is no way to stop receiving energy from the hammer-like transmitter. Tuning or changing the natural period of vibration of the receiver does little good.

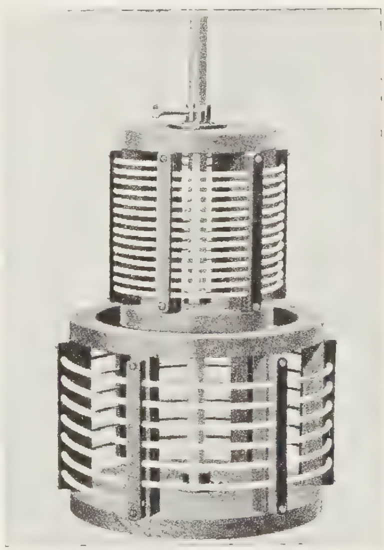


FIGURE 6. Oscillation Transformer. The coupling is changed by slipping the secondary endwise.

292. Oscillation Transformer. This lack of tuning led to coupled circuits using the oscillation transformer, the O.T., as abbreviated. The oscillation transformer consists of two coils with a few turns of heavy wire or copper ribbon, and is so arranged that the position of the coils can be moved with respect to each other. One coil, the primary, is connected to the transmitting condenser and the other coil, the secondary, is

connected to the aerial and the ground. Figure 6 is an oscillation transformer. A spark gap is placed in the primary circuit. An

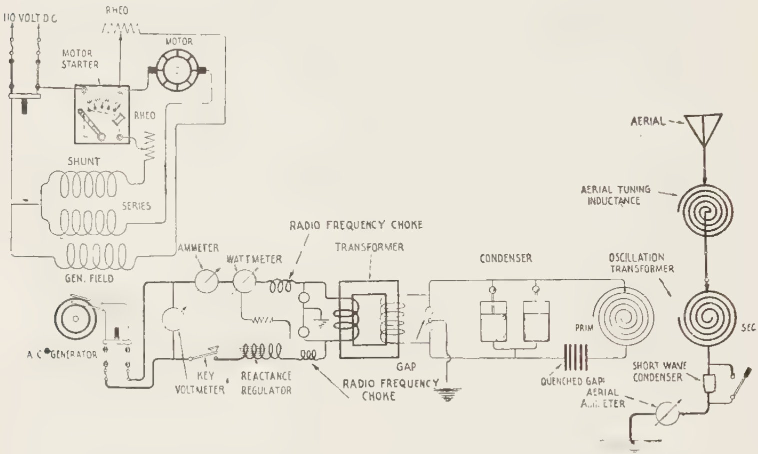


FIGURE 7. Fundamental Circuit of Spark Transmitter.

induction coil or high potential transformer is used to charge the glass plate oil condenser or Leyden jar. When the potential of the condenser is raised to a certain potential, a spark passes across the gap discharging the condenser through the coil. Both primary and secondary are tuned to the desired wave length by changing the inductance of the coil by varying the number of turns. Figure 7 is a diagram of a spark transmitter. Figure 8 shows a glass plate transmitting condenser.

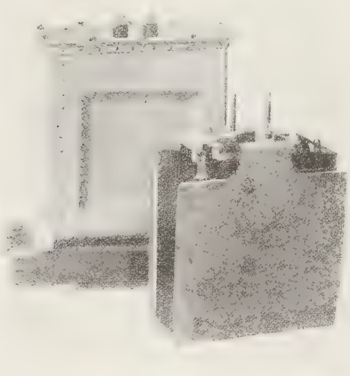


FIGURE 8. Glass Plate Transmitting Condenser.

The energy is first stored in the condenser and then upon discharge the energy is in the oscillating primary circuit. Since the secondary is inductively coupled to the primary, the secondary absorbs the energy and an oscillating current is set up in the aerial which is connected in the sec-

ondary circuit. The current in the aerial sets up electromagnetic waves and part of the energy is radiated into space. This last energy is the useful energy which transmits the signal.

The above is illustrated in Figure 18, Chapter XV, where we have an aerial radiating damped waves, which are represented by a sine curve extending from the transmitting aerial to the receiving aerial. The waves induce an E.M.F. in the receiving aerial, and radio frequency current is caused to run up and down the aerial. This current induces an E.M.F. into the receiver which is coupled to the aerial. The secondary current is amplified by tuning and is detected by the receiving tube. This detection causes intelligible sounds in the telephone. The primary circuit has the large resistance of the spark gap and is soon rendered nonconducting and need not be considered. The energy has been transferred to the aerial which has small resistance and will oscillate a large number of times before the energy is all dissipated. Thus, we have a long train of waves to which the receiving aerial can be tuned exactly while any other receiver can be tuned to a wave of different frequency and will thus be unable to pick up this station. The station can be "tuned out" by the receiver, since the transmitter gives out a long train of waves.

293. Coupled Pendulum. As an aid in understanding what takes place, let us set up a coupled pendulum, Figure 9. The pendulum can be made very simply with four balls tied to the ends of cords. Support a horizontal rod or bar about two feet long. Under this bar support a light wooden piece about fifteen or twenty inches long, with strings about two inches in length. To this light strip fasten the four pendulums. Arrange so that the length of the strings can be adjusted. Having two of these pendulums mounted so as to have the same length, start one of these to vibrating. If they have the same period, the second pendulum of the same length will begin to vibrate with increasing amplitude. The amplitude of the first will rapidly decrease until the vibration ceases. Then the second one is vibrating and has practically all the energy. The other two will spasmodically start to move,

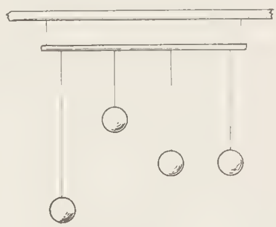


FIGURE 9.

hesitate and quit. They are so tuned that the vibration of the first can not be picked up. Hold the first, and the second will vibrate for a long time. If the first pendulum is not removed when it has given up its energy to the second, it will reabsorb the energy from the second pendulum. This periodic exchange will keep up until both cease vibrating.

This exchange is what takes place in the coupled electric oscillators. First all the energy is in the primary. This is absorbed by the secondary, reabsorbed by the primary, and again absorbed by the secondary.

294. Change of Phase. Figure 20, Chapter XV, shows the alternate change of amplitude in the two pendulums, or the change of current in the two circuits.

If one pays close attention to the two pendulums he will notice that they do not vibrate together. They at first seem to be moving in opposite directions. On closer observation they will be seen to be neither exactly opposite in phase or exactly in phase. The second lags behind the first, while absorbing motion, and the the first lags behind the second while it is absorbing from No. 2. If No. 1 lags behind No. 2 one quarter of a vibration while No. 1 is absorbing from No. 2, and then if No. 2 lags behind No. 1 while No. 2 is absorbing from No. 1, then the two sets of vibrations of pendulum No. 2 are in opposite phase.

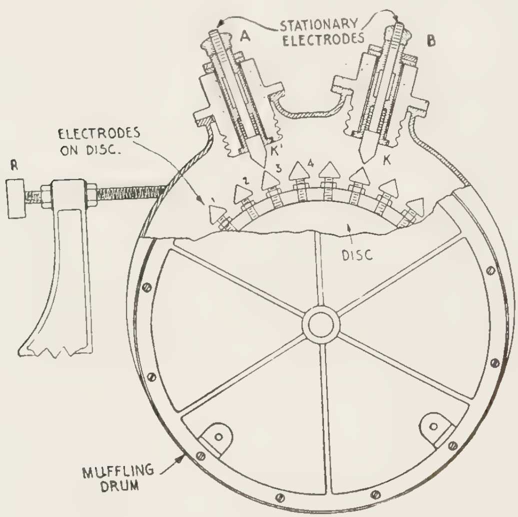


FIGURE 10. Synchronous Rotary Spark Gap.

What is the effect on a distant receiving aerial? The current begins to build up due to the first waves from the transmitter; in a short time the waves die out and then build

up in opposite phase and oppose the current that is flowing in the receiving aerial.

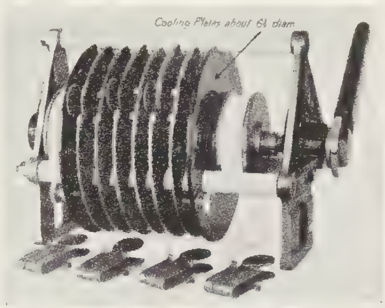


FIGURE 11. Multiple Quenched Spark Gap.

This, together with other coupling effects, makes the wave very broad, very inefficient and hard to tune out.

One remedy for this change of phase is to use looser coupling, move the coils farther apart, and the other remedy is to use a better spark gap.

295. Rotary Gap. The rotary gap is one which has one of the terminals mounted on a wheel. When the two terminals are close together the spark starts and before there is time for the primary to absorb energy again from the secondary the moving terminal is so far removed the resistance is infinite so that the primary does not reabsorb the energy Figure 10 shows a rotary gap.

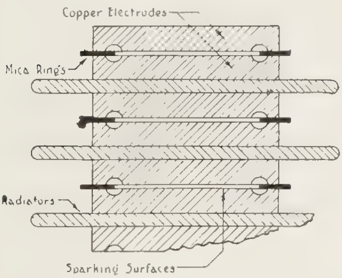


FIGURE 12.

296. Quenched Gap. The quenched gap is one made of a large number of short gaps in series between metal plates. There is so much cooling surface that the vapors cool off very rapidly and lose their conductivity, and the resistance of the primary becomes so large that the absorbed currents do not build up. Figure 11 shows a picture of a quenched gap. Figure 12 shows a section of the gap.

As an illustration using the pendulums: if after the first pendulum has given up its energy to the primary we hold it or remove it, the second pendulum will continue to vibrate until it runs down as an ordinary pendulum should do. This illustrates a quenched gap. Before the primary can reabsorb from the secondary the gap has cooled and become nonconducting.

297. Buzzer Excitation. The buzzer when used with a wave meter is a simple spark or damped wave transmitter. The buzzer closes the circuit, the current from the battery flows through the coil and the condenser is charged up, the potential being a fraction of a volt. When the buzzer opens the circuit the condenser dis-

FIGURE 13. Complete Ship Installation, $1\frac{1}{2}$ Kw (About 1920) (Radio Communication Co., Ltd.)

charges through the coil and the frequency of the oscillation is that of the circuit, $n=1/(2\pi\sqrt{LC})$.

298. Damped Wave Station. A damped wave station consists of a high potential condenser connected in series with the primary of an oscillation transformer and a spark gap. The condenser is connected to a high potential 60 cycle transformer when a rotary or quenched gap is used or to a 500 cycle high potential transformer when the gap is made synchronous. The secondary of the oscillation transformer is connected to the aerial. The diagram of the connections is given in Figure 7. Figure 13 is a reproduction of

a photograph of the inside of a ship's wireless cabin containing a spark transmitter. Figure 14 is a 20 Kw 500 cycle spark transmit-

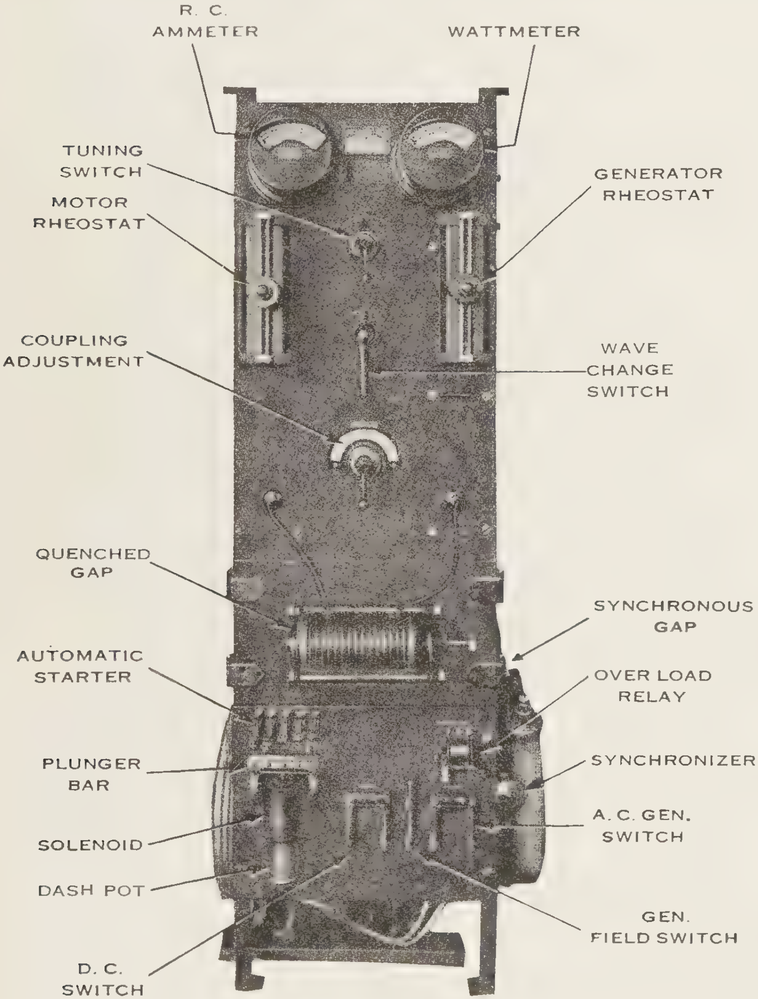


FIGURE 14.

ter, Type 8, of the Radio Marine Corporation of America.[F] Most of these have been converted into tube sets—the ET3628 set.

CHAPTER XXII

LONG WAVE C.W. TRANSMITTERS

299. The Arc Transmitter. The Poulsen arc is a means of generating continuous waves, or rather alternating current of constant amplitude. The general action of the arc generator can be illustrated by the Duddell singing arc. If an ordinary arc lamp operated on a 110 volt D.C. line has a condenser and an inductance connected around it as in Figure 1, there will be an audible note heard from the arc, provided the values of the inductance and capacity are right and the carbons are hard carbons. For details see Experiment 115, "Experimental Radio." The Poulsen arc works on the same principle as the Duddell arc, but due to the construction it is much more efficient.

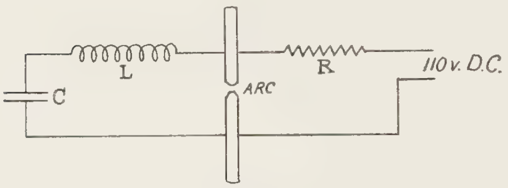


FIGURE 1.

The action of both these arcs depends on the fact that when the current in an arc increases, the potential across the arc diminishes. On account of this fact it is necessary to have a resistance in series with an arc lamp. The heavy line in Figure 2 gives the relation between the potential across the arc and current.

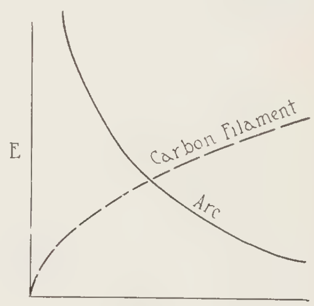


FIGURE 2.

300. Negative Resistance. The tangent to this line has a negative slope. On account of this negative slope the arc is said to have a negative resistance. It will be noted that in order to have a negative resistance we must define the resistance as follows: $R = dE/dI$ instead of by the equation, $R = E/I$.

It will be seen that both the current and E.M.F. have positive values. The broken curve in Figure 2 represents the relation between E and I in a carbon filament lamp. In the carbon filament the resistance decreases as the temperature increases, but the resistance is positive for all values of E and I, whether defined by $R = E/I$, or by $R = dE/dI$.

301. Action of the Oscillating Arc. In Figure 1 if we have a current flowing in the arc the condenser will be charged to a certain potential. If the current through the arc increases accidentally, then the condenser will discharge and increase the current. This in turn lowers the potential and hastens the discharge of the condenser. The current from the condenser flows through the inductance and the effect of an inductance is to tend to keep the current flowing in the same direction after the condenser is completely discharged and thus the potential of the condenser becomes negative. When the current through the coil becomes zero, the current through the arc diminishes, the potential across the arc rises and the condenser is charged by a current flowing through the coil in the opposite direction. Then the operations are repeated and we have an alternating current flowing through the coil and condenser. The frequency of this current will be the natural frequency of the circuit LC.

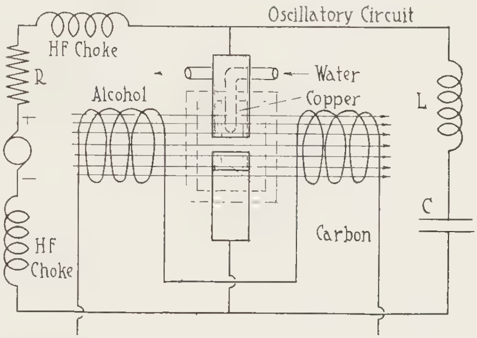


FIGURE 3

302. Poulsen Arc. The Poulsen arc uses copper and carbon terminals burning in an atmosphere of inert gas. The positive copper terminal is water cooled and the negative carbon terminal is rotated slowly in order to prevent pitting and uneven burning. To make the arc more unstable a magnetic field is placed at right angles to the arc. This tends to "blow the arc out." The inert gas atmosphere is supplied by alcohol dripping into the arc chamber.

The water cooled terminal, atmosphere of hydrogen, and the magnetic blow out makes the current through the arc drop to zero values, thus increasing the efficiency of the arc as a generator of high frequency current. Figure 3 is a diagrammatic drawing of the arc and circuit. Figure 4 is the Federal arc transmitter installed at Annapolis.]

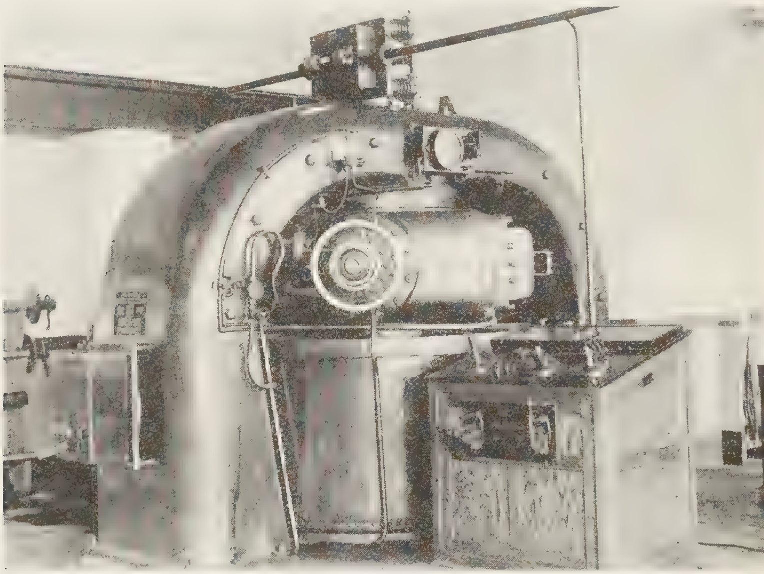


FIGURE 4. 500 kilowatt arc transmitter installed at Annapolis Md., by the Federal Telegraph Company.

303. Signaling. The arc is rather sluggish in starting to oscillate, so it is not feasible to key by opening and closing the power circuit. The arc must be allowed to operate all the time. There are two general methods of operation in use, the compensation method, and the uni-wave method. In the compensation method a turn or two of the coil of the inductance is shorted, thus changing the frequency of the oscillation.

This changes the tone or the frequency of the beat note as heard at the receiver using the heterodyne method of reception. A "chopper" can be placed in this short circuited circuit making

it possible to receive signals with a crystal receiver when the key is closed. Figure 5 gives the simple diagram.

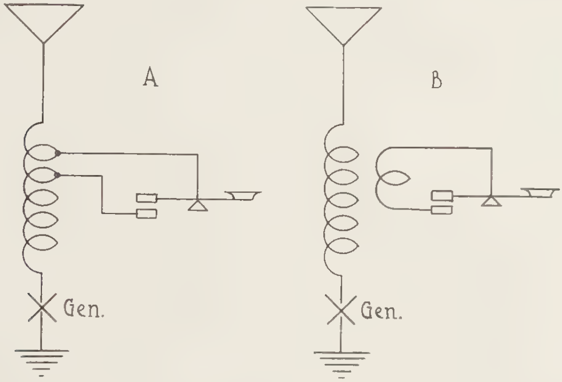


FIGURE 5

The uni-wave method consists of a dummy circuit with the same constants as the aerial circuit and a key which throws the connections from the dummy circuit to the aerial circuit. Thus the waves are sent out only when the key is closed. Figure 6 gives the diagrammatic circuit.

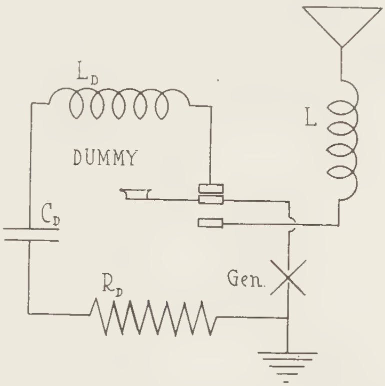


FIGURE 6.

Arc transmitters are used in trans-Atlantic service and on larger ships which use relatively long waves. The shorter wave installations are being replaced by tube stations.

304. Alternators. Several attempts have been made to make a high frequency alternator. One of the first was to have a number of damped wave circuits, six, perhaps. All of these circuits were connected inductively to the same secondary circuit. By timing a rotary spark gap the various circuits were discharged in rotation and so synchronized that one of the circuits was acting

inductively on the secondary circuit all the time. When these were synchronized properly the effects in the secondary were all in phase and produced a current of constant amplitude. The most successful alternator is the Alexanderson alternator.

305. Alexanderson Alternator. The Alexanderson alternator for generation of high frequency current, consists of stationary armature windings about laminated pole pieces. These magnets resemble horse shoe magnets in that the north and south poles are separated by a small gap. The polarity and strength of these magnets remain fixed except that the reluctance of the magnetic circuit is varied by means of a high speed rotor which rotates between the pole pieces with small clearance. Around the periphery or outer edge of this rotor, slots are cut into the steel and these slots are filled with a non-magnetic material. As the rotor rotates, the field has a maximum value when steel is between the poles and a minimum value when the non-magnetic material is between the poles. One cycle is represented by the time of travel of the rotor a distance represented by the distance from the center of a slot to the center of the next slot. Figure 7 shows a section of the field and rotor. A cut-away view looking along the shaft, showing windings, is also shown. If one knows the number of poles and the speed of revolution the frequency can be obtained.

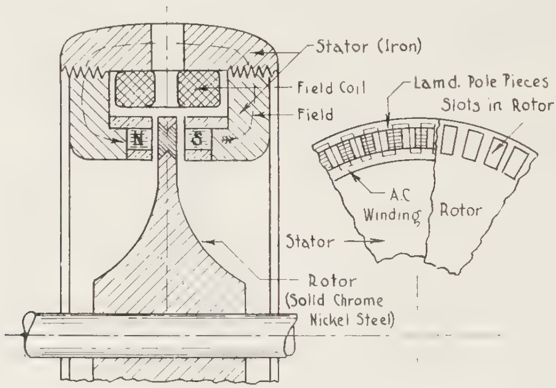


FIGURE 7.

The rotor has the peculiar shape, shown in Figure 7, in order to stand the mechanical forces produced by the high speed of

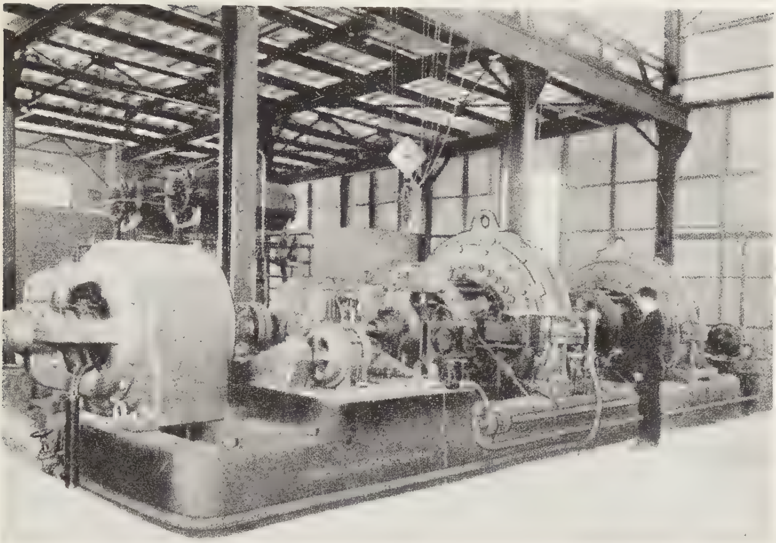


FIGURE 8. A 200-Killowatt Radio-frequency alternator. Installed at the Rocky Point station and used for trans-Atlantic radio-telegraphy.

revolution. The radial force produced on an ounce of the outer part of the rotor is calculated to be represented by tons. Figure 8 shows a picture of a 200 kilowatt Alexanderson alternator.

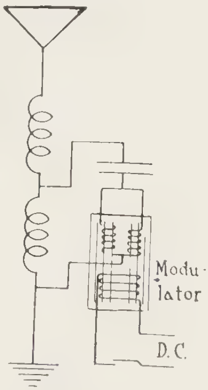


FIGURE 9.

The speed regulation is held automatically to within one-tenth of one per cent. One of the high frequency coils is tuned to a frequency slightly higher than the normal speed of the machine. This current passes through a transformer. In the secondary of this there is a rectifier. When the speed of the machine increases the rectified direct current increases. This increasing current acts on two variable impedances in the A.C. supply line. The increased direct current increases the impedance causing the motor to slow down. The energy of the alternator is fed into a multiple tuned aerial. Figure 6, Chapter XVIII.

This speed control acts on the same general principle as the magnetic modulator.

306. Magnetic Modulator. This depends upon the fact that the inductance of an iron core coil depends upon the permeability of the core. The permeability of iron depends on the field, H, and the field depends upon the current. By placing a coil around the core of an A.C. magnet through which a D.C. flows, the permeability can be changed and thus the inductance of the coil in the A.C. circuit is changed.

FIGURE 10. Central Operating room at 66 Broad St., New York City, of the R. C. A. Communications, Inc.

By means of this magnetic amplifier the power fed to the aerial is controlled. The aerial is connected to the alternator through a tuned circuit. Part of the inductance of this circuit is a coil on the magnetic amplifier, Figure 9. The D.C. through the coil tunes or detunes this circuit by changing the permeability of the iron core.

For details, see General Electric Review, Vol. 23, 1920.

Figure 10 is a picture of the operating room of the R. C. A. Communication Inc., where messages are received from and transmitted to all parts of the world.

CHAPTER XXIII

VACUUM TUBE TRANSMITTERS

307. Introduction. The most popular transmitter in use today is the tube transmitter. During the past five years most of the ship spark stations have been transformed into tube transmitters. In Chapter XIV, Vacuum Tube Oscillators, it was pointed out that when a tube was connected in certain ways it would become a generator of alternating current, the frequency of which depended upon the capacity and inductance in the circuit.

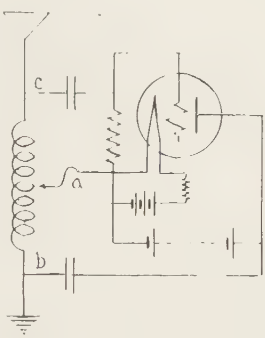


FIGURE 1.

308. Simple Transmitters. An aerial has capacity and inductance and is usually connected to a loading coil. Thus the tube can be connected to the aerial in such a manner as to oscillate. Figure 1 is a diagram of a tube connected to an aerial. It will be seen that if we think of the flat top and ground being the plates of the condenser we will have the Hartley shunt circuit which was diagrammed in Figure 8, IV, Chapter XIV. The coil, *L*, is the inductance and the aerial is the capacity. A grid condenser is placed in the grid, or *C* circuit. This, in conjunction with the grid leak resistance, *R*, can be adjusted to give the proper *C* battery bias, making a C battery unnecessary.

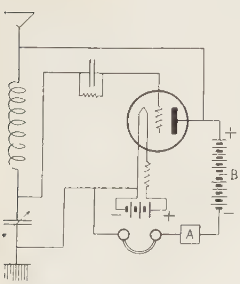


FIGURE 2.

Figure 2 is another circuit which by reference to Figure 8, XI, Chapter XIV, can be seen to be a Colpitts circuit, or split capacity circuit, as it is sometimes called. By referring to Figure 8,–X, and following the letters *a*, *b*, *c*, it is seen that the ground connection is a point between two condensers, or the point, *a*.

The plate, *b*, connection, and the grid, *c*, connection will be seen to be the same in both figures. All the early stations, telegraph and broadcast, were of these types in 1921–22–23.

The wave length of these stations depends upon the constants of the aerial and these may change due to swaying in the wind and other causes. Thus the wave length swings erratically from one value to another, when using this circuit. To remedy this variation, coupled transmitters were introduced.

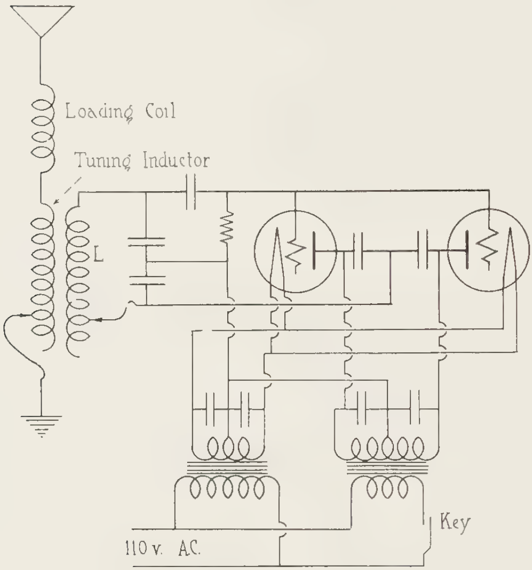


FIGURE 3.

309. Coupled Circuits. The better tube stations began coupling the aerial to the transmitter by inductive coupling. The tube was connected to an oscillating circuit and this was coupled inductively to the aerial coupling coil.

In commercial apparatus the oscillating circuit connected with the tube is called the tank circuit and the coil is spoken of as the tank inductance.

310. Marine Transmitters. Figure 3 is a simple diagram of the circuit of a marine transmitter of the Radio Marine Corporation of America, Model ET-3628 ACW tube transmitter. This transmitter is a P-8 spark transmitter converted into a tube transmitter. The circuit will be seen to be a Colpitts circuit. The tubes are UV 204, 250 watt tubes. Two tubes are used with self-rectified alternating current on the plates of the tubes. The high potential transformer has a mid-tap which connects to the filament circuit.

The plate of one tube is at a high positive potential, while the plate of the other tube is at a negative potential and therefore this second tube takes no current. First, tube No. 1, then tube No. 2 is generating current, Figure 4. This radio frequency current drops to zero twice in each cycle of the alternating current. The filament and plate currents are supplied by transformers which are connected to a 500 cycle A.C. generator which is driven by a D.C. motor. The key is in the low or generator side of the transformer. Thus the signals are made by interrupting the energy of the plate transformer.

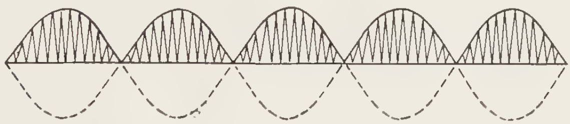


FIGURE 4.

The signals can be received from this transmitter by a crystal receiver, if necessary, since the transmitter is a modulated continuous transmitter. By means of switches this set can be adjusted quickly to any one of the following wave lengths: 600, 706, 750, 800, and 900 meters.

Figure 5 is the assembled set. Compare with Figure 14, Chapter XXI of the P-8 spark transmitter.

311. Master Oscillator Circuits. When the antenna is coupled to the oscillating circuit there is some induced effect from the aerial to the main oscillating circuit unless the coupling is very loose. This induced effect tends to make the wave length rather unsteady. It has been found that it is much better to have a single tube as a master oscillator, accordingly the tubes which feed the aerial are connected to the master oscillator so that in reality we have a radio frequency amplifier. The master oscillator sets the frequency and the current of this frequency is amplified by the other tubes and fed to the aerial.

In some circuits a very small tube is used as the master oscillator and a number of stages of amplification is placed between this and the last power tube.

Figure 6 shows a modified diagram of the circuit of the ET 3526 marine set. Two 50-watt tubes are used as master oscillators, and

six 50 watt tubes in parallel are used as the power tubes. The master oscillator tubes are connected in a Hartley circuit to the power circuit. Plate potential, 1000 volts, is fed to the plates through a choke coil. The grids of the tubes are connected to a

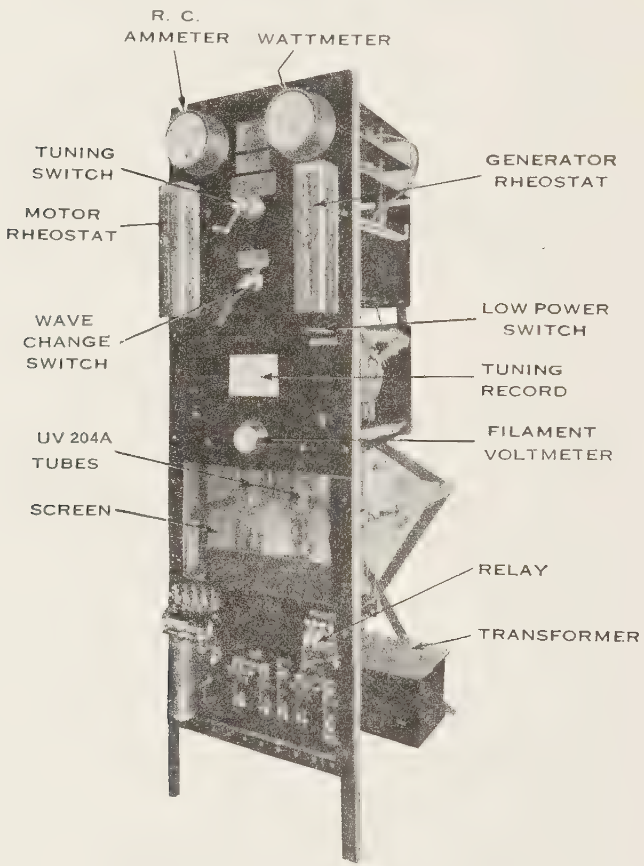


FIGURE 5. P-8 Converted Tube Transmitter type ET 3628. This is a tube transmitter made from a spark transmitter.

point G, on a resistance connected to the negative terminal of the generator. The chokes isolate the plates and the grids from the D.C. machine as far as radio frequency is concerned. A resistance in the grid circuit gives the proper grid bias when

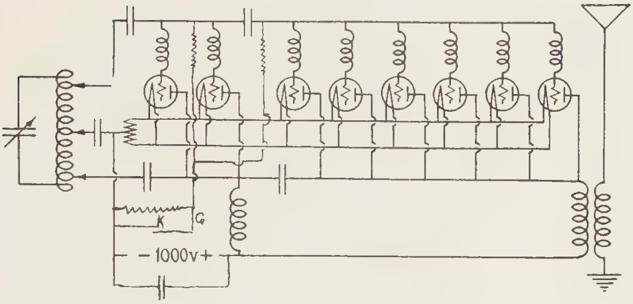


FIGURE 6.

operating. The power tubes are fed plate current through a coil which inductively connects with the aerial circuit. The radio frequency from these plates passes from the plates through the coupling coil to plus terminal of the generator through a blocking condenser to the negative terminal and then through the ground connection to the filaments of the tubes. The filaments of all tubes are at ground potential, the grids are connected together through a condenser and the plates of the master oscillators are isolated from the plates of the power tubes. The current in the plate circuit of the power tubes is controlled by the potential of the grids of the tubes which must follow the potential of the grids of the master oscillator

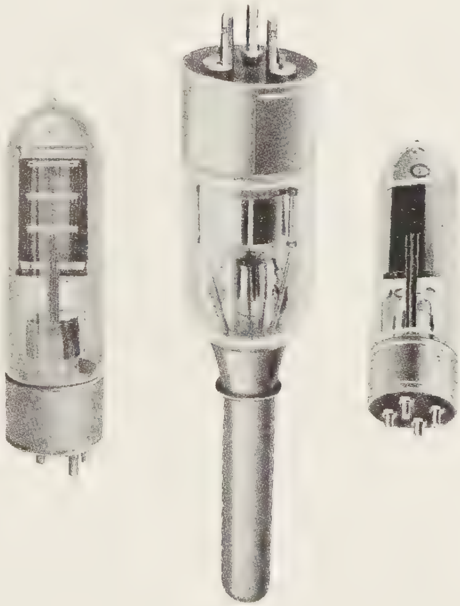


FIGURE 7. Two 50 watt tubes and a 1000 watt tube which can be used as ocillators.

tubes. Thus, the plate current of the power tubes is oscillatory. When the key is closed the point *G* is at the same potential as the negative terminal of the generator, which means that the grids have the proper negative bias with respect to the filament in order to oscillate. With the key open the tubes cease to oscillate because the potential of the grids are too much negative and the plate current of all tubes becomes small. Figure 7 is a picture of power tubes.

312. Short Waves. Before 1921 it was thought that in order to transmit any distance it was necessary to use long waves. Trans-Atlantic stations were using wave lengths in the thousands of meters; 200 meters or lower were turned over to the amateurs as worthless. In 1921 the amateurs attempted to transmit across the Atlantic, using their 200 meter equipment. The first attempt, in February, was not successful, but the second, in December, was received by many European amateurs, as well as by a representative of The American Radio Relay League who was sent to Scotland for the purpose. Many stations on the coast were heard in Europe, as well as several nearly 1000 miles inland. Many of these stations were amateur spark stations limited to 1 K.W. power.

In 1923, two-way communication was established on 100 meters. By 1924 many amateurs, as well as the U. S. Navy, had become interested in short wave transmission. At the present time amateur transmitters are licensed for 97 centimeters, 5, 20, 40, 80, 150 to 200 meters. In the list of Commercial Stations of the U. S. are stations licensed for waves as low as 5 meters.

313. Skip Distance. Soon after work on the short waves was undertaken it became apparent that short waves did not act like long waves in many respects. A station could be heard for a short distance—50 miles perhaps—and then at 800 or 1000 miles it could be heard again. The 800 miles was called the skip distance. From 800 miles the intensity falls off gradually to about 4000 miles by day. At night the skip distance may be 4000 miles, and then the intensity of signals will gradually fall off. The exact distance depends on the time of day and year.

This has been explained by assuming that some of the energy follows the surface of the earth and gradually is dissipated by absorption of the atmosphere due to ionization and other effects. Perhaps it may be said that the atmosphere near the earth's

surface is a poor dielectric. Some of the radiation passes in a straight line, perhaps, upward, making an angle with the earth's surface into the upper atmosphere where the absorption is not so great and then strikes the Heaviside layer and is reflected downward to the earth again thousands of miles from the place of starting. This reflection can be explained if we remember that a conductor is a reflector of electromagnetic waves and that the conductivity of a gas increases as it is rarefied. Some place in the upper atmosphere the pressure of the air is the same as that in a tube which has been evacuated to the pressure of best conduction. Another method is to assume that the rays bend more or less gradually in the upper atmosphere and finally return to the earth much as the light does in warm air when a mirage is formed.

FIGURE 8.

Figure 8 is a diagram of what is supposed to happen. Thus in long distance work with short waves the signal is shot upward at a certain angle and then bounced down again onto the receiving station.

The Heaviside layer is at an indefinite height and usually is changing from one altitude to another. The motions of the atmosphere may at times make this surface very rough, something like the under side of a storm cloud.

314. Short Wave Antenna. We have said that an antenna might be a Marconi antenna—one whose fundamental wave length is about four times the height of the antenna, or it might be a Hertzian antenna—one not connected to the ground and whose length is one-half the fundamental wave length. The Marconi type, like a closed organ pipe, can vibrate so its length is 1/4, 3/4, 5/4, and any odd fourths of a wave length. The Hertzian is like an open

organ pipe in that its length is 1/2, 2/2, 3/2, etc. wave length. These vibrations are represented in Figures 3 and 4, Chapter XVIII.

It will be seen that when an aerial is vibrating in parts or to an overtone of the fundamental that the wave radiated from one part of the aerial will be out of phase with that from another part of the aerial. There will be interference patterns something like the interference pattern about a tuning fork. For best results the aerial, whether Marconi or Hertzian, must respond to the fundamental. Another theory of the cause of skip distance is to suppose that the useful energy is that radiated at a rather low angle and then reflected to a distant point while the high angle, Figure 8, radiation passes upward and out into space. At a point near the surface of the earth when using low angle radiation, the radiations from the various sections, loops, interfere with each other, leaving most of the energy radiated upwards into space beyond the Heaviside layer. Just why the radiation penetrates the Heaviside layer at perpendicular incidence is not clear.

315. Feeder Wires. The effects mentioned in the last paragraph make it imperative that we use the fundamental frequency of the aerial, or rather that we construct an aerial which will have a fundamental frequency equal to the frequency of the set. For short waves, 5 meters, say, the aerial becomes rather short and this must be coupled to the set, placing the aerial inside the building, unless we hang the set on a pole and operate it by remote control. The necessity of power lines to the set on the pole complicates this last arrangement. To transmit the energy from set to aerial feeder wires are used. There are two general types, current feed and voltage feed. Figure 9 shows two current feed systems. P is the primary or tank coil of the oscillator and S is a coil inserted in the middle of the Hertzian aerial.

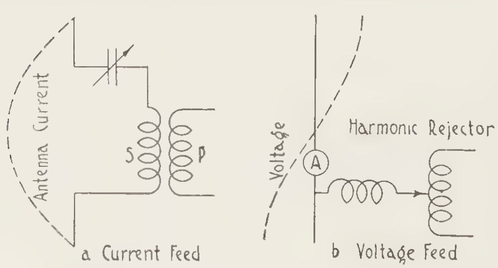


FIGURE 9.

Figure 9b is a voltage feed. A single wire is connected to a voltage loop, or point of great change of potential, of the oscillator to a loop of the antenna. A choke coil can be inserted to choke out the higher harmonics. This method is objectionable since the set and aerial are conductively coupled and the feed wire radiates, as well as the aerial.

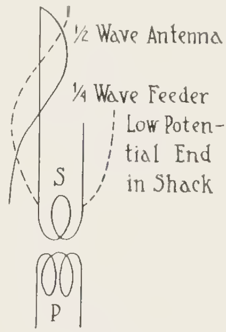


FIGURE 10.

A feed system called the Zeppelin Antenna is, perhaps, the most satisfactory. Figure 10 illustrates the principle. P is the transmitter coil and S is a turn or two of wire. If to one side of S a wire, whose length is 1/4 wave, is connected and to the other a wire, whose length is 3/4 wave, and these wires are placed in parallel, the space between being a few centimeters, the radiation from the parallel wires will annul each other and we have a wire whose length is 1/2 wave free to radiate at the end. This, then, is in reality a simple Hertzian antenna removed from the set.

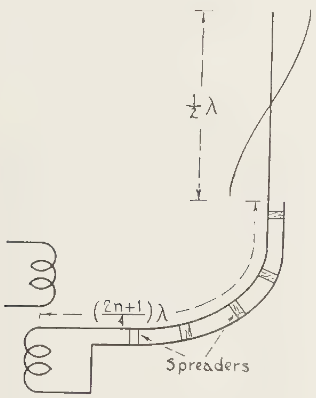


FIGURE 11.

The short wire may be an odd quarter wave long and the long wire a half wave length longer, and we have a Leecher wire system leading to a simple Hertzian antenna. Figure 11 shows the general construction. It is best to make the feed wires no longer than necessary.

316. Reflection of Short Waves. Short waves, due to the fact that they are short, or rather due to the fact that the antennae are short, lend themselves to reflection experiments.

In Figure 12 suppose we have a Hertzian antenna, A, coupled to an oscillator. At a convenient distance we have a large sheet of copper whose thickness is such that the resistance can be neglected. The electromagnetic field at R, from the aerial A, will set up currents in the conductor.

According to Lenz's law, the effect is in the direction to oppose the cause, and the current in *R* will be of right value and direction to produce a field just equal and opposite to the field from the aerial *A* at *R*. Back of *R*, then, there will be two equal and opposite fields traveling at the same velocity in the same direction. The resultant field will be zero. In front of *R* there will be an equal and opposite field traveling in the opposite direction, or toward *A*. If the space between *A* and *R* is the proper length, an odd quarter of waves, there will be stationary waves set up with *A* as a point of great disturbance, or an antinode, and with *B* as a node, or a point of no disturbance. At an antinode the transmitted and reflected waves are always in the same phase so that if the distance is a quarter or odd quarter, the wave from the reflector which is traveling toward the left in the figure will be in phase with the wave from the transmitter which passes out on the left side of *A*.

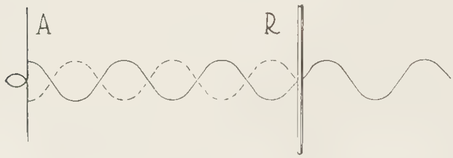


FIGURE 12.

If instead of a large sheet of metal at *R* a copper or brass rod whose length is such as to respond to the wave, or a rod whose length is 1/2 wave long, is placed at *R*, we will have the same effect, and the field in front of *A* will be found to be much increased. If other rods are placed on either side of the first rod, *R*, Figure 13, and so placed that the combined distance from *A* to *R* and to a plane perpendicular to the line joining *A* and *R* is equal to a half wave, we will have a semi-parabolic reflector. It is parabolic with respect to the horizontal plane but not with respect to a vertical plane. Thus we have a reflector which will throw a beam of radiation in one direction.

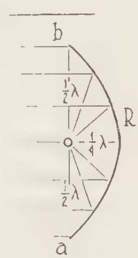


FIGURE 13.

Reflectors have been made which have met with some success for long distance transmission. The reflector can be set at the right angle to transmit the wave to the Heaviside layer so as to reflect down on the receiving station in another continent.

Figure 14 is a picture of a modern amateur transmitting set for the 3500 kilocycle band. This set is operated by remote

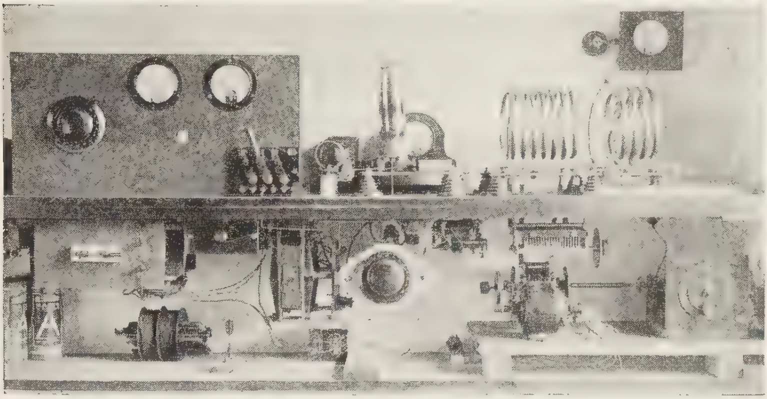


FIGURE 14. A Modern Amateur Transmitting Set. Courtesy Q S T.

control. Figure 15 is a schematic diagram of the connections of the set illustrated above. Figure 16 is a variable transmitting condenser.

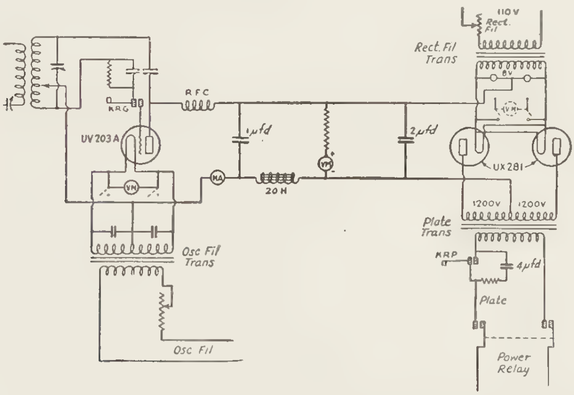


FIGURE 15. Schematic Transmitter and Plate Supply Diagram of the set show in Figure 14.

317. Transmitting Tubes. Transmitting tubes are, in general, the same in construction as the small tubes. With high potential on the plate special precautions must be taken to insulate the plate

TRANSMITTING TUBE DATA

Manufacturer	Type Number	Rating (Watts) Oscillator	Safe Continuous Plate Dissipation (Watts	Filament Volts	Filament Amperes	Type of Filament	Plate Volts	Plate Current (Milli-amps.)
General Elec. Co. (RCA)	UV-202	5	12.5	7.5	2.35	Tungsten	350	50
	UV-203	50	100	10.0	6.5	Tungsten	1,000	150
	UV-203A	50	100	10.0	3.25	XL-Tungsten	1,000	140
	UV-204	250	250	11.0	14.75	Tungsten	2,000	250
	UV-204A	250	250	11.0	3.85	XL-Tungsten	2,000	250
	UV-205	250	250	20.0	3.85	XL-Tungsten	2,000	250
	UV-206	1,000	350	11.0	14.75	Tungsten	10,000	40
	UV-207	20,000	10,000	22.0	52.0	Tungsten	15,000	1.7 amp.
	UV-208	5,000	1,500	22.0	24.5	Tungsten	15,000	225
	UX-210	7.5	—	7.5	1.25	XL-Tungsten	350	50
	UV-211	50	100	10.0	3.25	XL-Tungsten	1,000	100
	UV-851	1,000	—	11.0	15.0	—	2,000	—
	UX-852	75	100	10.0	3.25	XL-Tungsten	2,000–3,000	75

TRANSMITTING TUBE DATA (*Continued*)

Western Electric	220-B (water cooled)	10,000	10,000	22.0	42.0	—	10,000	650 to 1,500
	212-D	250	—	14.0	6.0	Oxide	1,500	175
	211-D	50	65	10.0	3.0	Oxide	750 to 1,000	65
	228-A	1,000	350	—	—	—	10,000	—
	205-D	5	-	7.0	1.35	Oxide	350	40
	215-A (peanut)	—	—	1.25	—	Oxide	$22\frac{1}{2}$ det. 45 amp.	1 to 3
	222-A Rectifier	5,000 to 10,000	—	21.0	—	—	9,500 to 10,500	500 max.
DeForest	H	60 to 100	—	10.0	2.35	Tungsten	500 to 3,000	40–50
R.C.A.	842	8	12	7.5	1.25		425	28 mil
	211	75	100	10.	3.25		1,000	175
	865	7.5	15	7.5	2	Screen grid	500	21
	860	75	100	10	3.25	Screen grid	2,000	100
	861	500	—	11	11	Screen grid	3,000	600
Rectifier	866					Hot cathode mercury vapor	5,000	

from the rest of the tube. In the larger tubes the plate, and often the grid connection, is led through the tube at a point far removed from the filament. For short wave work special precautions must be taken to keep the inter electrode capacity of the tube low.

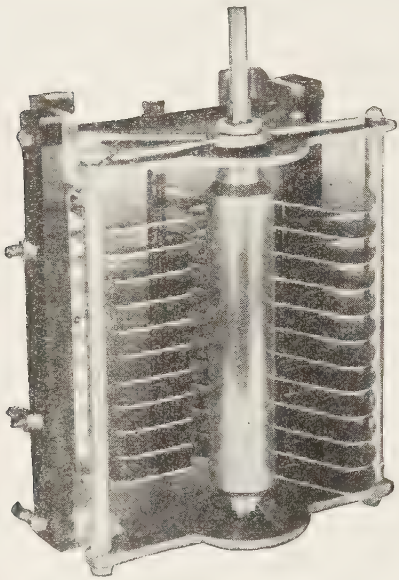


FIGURE 16.

Screen grid transmitting tubes have been developed in order to minimize the capacity effects in tubes.

The preceding table gives transmitting data for a number of tubes. The various methods of numbering tubes is perplexing and it is almost impossible to give all the numbers.

318. Crystal Control. Oscillating Crystals. Certain crystals are known as piezo-electric crystals. Quartz is one of the piezo-electric crystals. These crystals have the property of developing electric charges on their surfaces when put under tension or pressure. This effect is best shown when the crystal is cut into plates or rods whose geometrical outlines coincide with certain axes of the crystal.

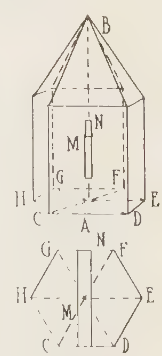


FIGURE 17.

Figure 17 is a diagram of a hexagonal crystal of quartz. The line *AB* represents the optical axis of the crystal. This is the line in which there is no double refraction. Along other directions light is doubly refracted. Directions parallel to the lines *CF*, *DG*, and *EH*, are said to be along the electric axes. If a plate such as *MN* is cut perpendicular to the electric axis, *EH*, and contains the optical axis, *AB*, parallel to the faces we have a plate suitable for an oscillating crystal. If the plate is placed under

pressure one face is found to be positively charged and the other is found to be negatively charged. If the crystal were placed under a tension perpendicular to the faces the charges on the surfaces would be of opposite kinds. If the faces are charged the crystal will be extended or compressed along the electric axis.

The crystal can be thought of as being a coil spring. When this spring is compressed a positive charge is developed on one end and a negative charge appears at the other. If the spring is stretched the charges are reversed. On the other hand, if the ends are charged the spring is compressed or elongated, depending upon the charge.

If the spring is compressed and suddenly released it will vibrate at a certain frequency depending on the constants of the spring. If an electric circuit is connected with the ends of the spring the vibrating spring and the changing charges will tend to make the circuit oscillate. If the natural frequency of the spring is the same as the natural frequency of the circuit the vibrations or electrical oscillations will be greater. If by some means some of the electrical energy in the electrical circuit is amplified so as to charge the ends, this charging effect will cause the spring to vibrate, and this will cause the electrical circuit to oscillate.

FIGURE 18.

The quartz plate is such a spring. Figure 18 is a picture of quartz plates. The natural frequency of the plate depends upon the thickness of the plate and upon the elasticity of the quartz. The frequency of a brass rod when stroked with a resined piece of leather, depends upon the length of the brass rod and upon the elasticity of brass.

If the quartz plate is placed between two parallel plates or in a crystal holder, Figure 19, and connected to a vacuum tube as in Figure 20, oscillations will be set up due to the capacity coupling through the tube, when the frequency of the electrical circuit is the same as the natural vibration frequency of the quartz plate. It is found that this frequency is, to a certain extent, independent of the constants of the electrical circuit. If the circuit is oscillating and one has a second oscillating tube circuit heterodyned with it, a certain note will be heard in the phones of the second oscillator. If the condenser of the crystal oscillator circuit is changed the frequency does not change but remains constant. When the capacity is changed too much the circuit ceases to oscillate. Thus the crystal controls the frequency. A crystal controlled circuit has a constant frequency, the frequency being that of the crystal which controls the frequency of the circuit.

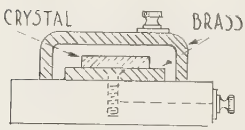


FIGURE 19.

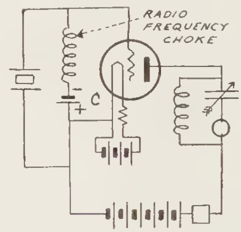


FIGURE 20.

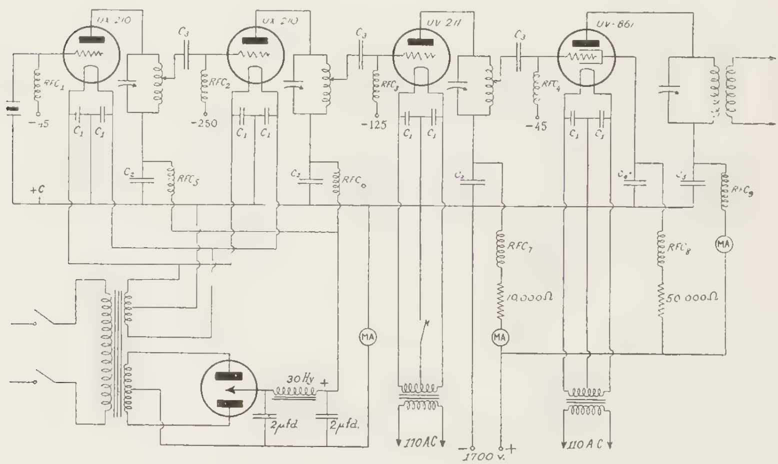


FIGURE 21.

It has been found that the frequency of the crystal depends upon temperature the same as the "velocity of sound in brass" depends upon the temperature of the brass. In order to insure constant frequency the crystal is placed in compartments which are automatically held to a certain temperature. Figures 19 and 20, Chapter XXIV, are diagrams of crystal controlled stations.

319. Harmonic Vibrations. It is found that the crystal will resonate at certain harmonic vibrations—multiples of the fundamental. Often instead of using a crystal at its fundamental frequency an overtone frequency is used. This is usually the case with short wave stations. The frequency is inversely proportional to the thickness. A crystal to resonate at a high fundamental frequency must be very thin and is therefore, liable to break.

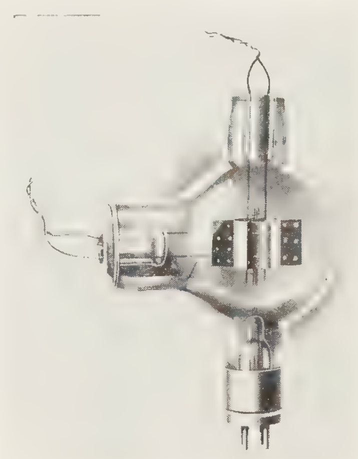


FIGURE 22. R. C. A. Transmitting Tube. UX852.

320. Frequency Doubler Circuits. Often to get the frequency high enough a circuit is caused to vibrate at a fundamental frequency, and a second circuit is tuned to the overtone of this circuit. This doubling may be repeated several times. Thus if the fundamental frequency is constant the doubles of this frequency will be constant.

Figure 21 is a circuit in which frequency doubling is used. The doubling takes place twice. The first tube oscillates at 3500 kilocycles, the second at 7000 kilocycles, and the third and the power tube oscillate at 14000 kilocycles. It will be noted that the last, the power tube, is a screen grid tube.

321. Ultra Sonic Vibrations. If a crystal is excited by an oscillating current from a powerful amplifier it can be made to vibrate with a comparatively large amplitude. The vibrating quartz sets the air into vibrations and gives a very intense "sound" at a frequency which cannot be heard. If glass rods are set into vibration by the crystals they "slide" in the hand at a frequency which

makes them feel hot. If heat is the kinetic energy of the molecule they are hot. The vibration is so fast that the frequency approaches

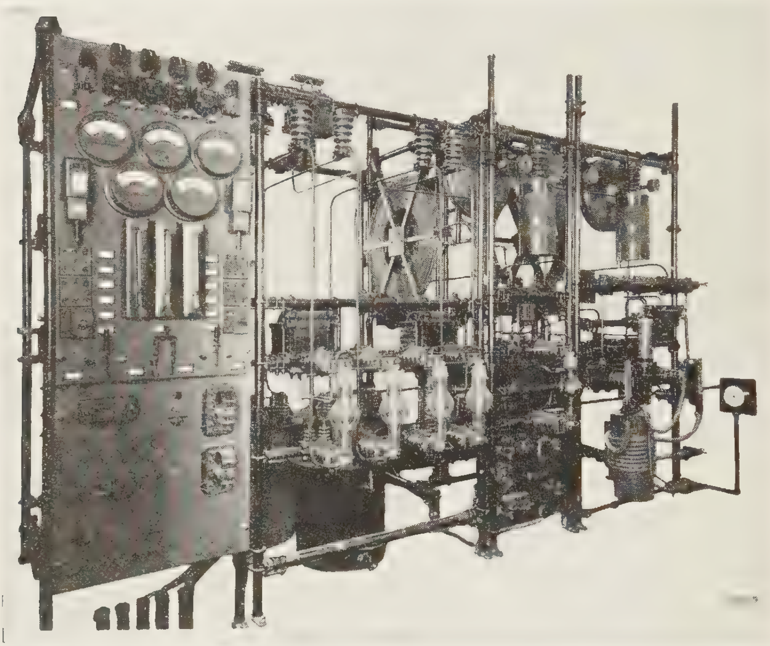


FIGURE 23. Type of transmitter used at W C C, Chatham, Mass. A marine radio coastal station owned and operated by the Radiomarine Corp. of America.

molecular vibration. Figure 22 is a Radio Corporation of America tube built especially for short wave work.

Figure 23 is the Transmitter at Chatham, Massachusetts.

CHAPTER XXIV

RADIO TELEPHONE

322. Introduction. The radio telephone is a special case of modulated continuous waves, M.C.W. In Chapter IX, Detectors, it has been pointed out that continuous waves, C.W., can not be detected unless they are "chopped" or modulated. We have said that damped waves can be considered to be modulated waves. Modulated waves are high frequency waves in which the intensity or amplitude of the waves changes periodically. The amplitude of the wave depends on the current amplitude. In alternating current we have the equation, $I_{\text{virt.}} = (I_{\max}/\sqrt{2})$, showing the relation of the virtual current to the maximum value. The maximum value, of course, is the amplitude of the current. The amplitude of 2 amperes A.C. is twice the amplitude of 1 ampere A.C. A modulated wave is one in which the radio frequency current fluctuates in value. It is usually assumed that the frequency of fluctuation is at audio frequency. In a radio telephone transmitter the current fluctuates in value at voice frequency.

It must be remembered that ordinary thermal ammeters, cannot follow this fluctuation, but give average values of the current.

323. Modulation. In the marine code transmitter, 3628, Figure 3, Chapter XXIII, we have a case of modulation with 60 cycle current. This will give a note of 120 frequency, since both sides of the A.C. are rectified. This modulation is due to the fact that the potential of the plate of the oscillating tube changes. This is known as plate modulation and is the method which is usually used in the radio telephone.

The methods of modulation in common use are plate modulation, grid modulation, and absorption modulation. These all use a carrier wave of constant frequency. Another method of modulation is known as frequency modulation.

324. Absorption Modulation. Perhaps the most simple method of modulation, as far as apparatus is concerned, is absorption modulation. If we have an oscillating tube connected as in

Figure 1 or in any other manner so the tube will oscillate, and if it induces an oscillating current in the aerial circuit and if we place an ordinary carbon microphone in the aerial, the current in the aerial can be made to vary in amplitude in unison with the voice frequency. If one remembers the principle of the carbon microphone this will be readily understood. The microphone depends upon the fact that the resistance of carbon varies with pressure. When the pressure on the diaphragm is increased by the air voice wave, the resistance of the microphone is diminished and the current is increased. When the pressure is diminished the resistance is increased and the current is diminished. Thus we have the current varying with the voice frequency.

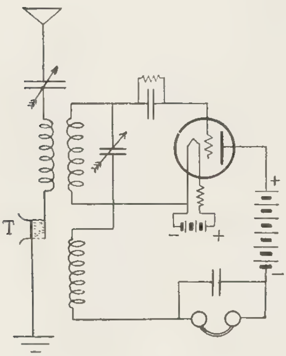


FIGURE 1.

This method can be demonstrated very easily. If one has a regenerative receiver and lets it oscillate, there will be a current in the aerial circuit. It is this current in the aerial which is the objectional feature of this type of receivers,—objectional from your neighbors' standpoint. If an ordinary microphone is placed in the aerial it is possible to telephone by this method for a distance of a city block or two.

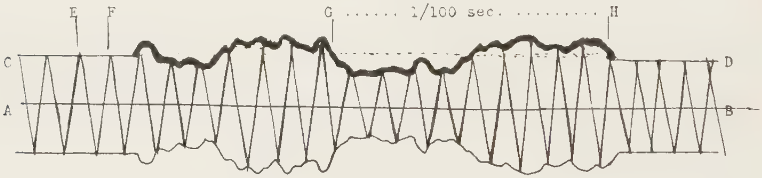


FIGURE 2.

Instead of placing the microphone in series with the aerial it can be connected to a coil which is coupled rather closely to the coil in the aerial.

325. Diagram of Modulation. Modulated current or waves can be represented as in Figure 2. The amplitude of the carrier wave is represented by the line AC. This is the amplitude when the

microphone is not disturbed or when no one is speaking into the microphone. The zigzag lines represent the high frequency current or carrier wave. The distance *EF* represents a time interval of 1/1000 second. If the wave length of the station is 300 meters or frequency of one million, there will be 1000 vibrations between *E* and *F*. It is impossible to draw the thousand vibrations in the diagram, so it must be remembered that one vibration on the diagram represents one thousand actual vibrations. If the microphone is actuated by some sound such as, a in "father," the amplitude of the current in the aerial will vary in some such manner as that represented by the heavy line in the diagram.

The distance from *G* to *H* represents 1/100 of a second. If one remembers that there is 1000 vibration between each zigzag line it can be seen that peaks will fit into all the small variations or overtones of the voice frequency. If the wave length were 15000 meters the frequency would be 20000 cycles per second. In the diagram one zigzag line will represent only 20 vibrations and it will be seen that the higher overtones will be lost. The quality of the tone of transmission can not be very good on long waves. This figure can represent a voice modulated wave whether it is absorption, grid, or plate modulation which is used in the transmitter. That method of modulation is the best which will cause the amplitude of the high frequency current to vary in a manner which is the nearest to variation of the voice frequency.

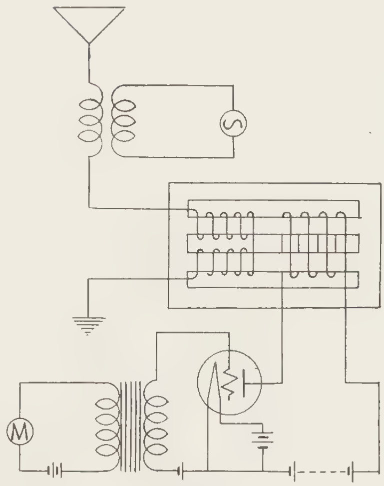


FIGURE 3.

326. Magnetic Modulator. The magnetic modulator is a device which has been used in connection with Alexanderson alternators for radio telephone transmission. Figure 3 shows the principle. The theory of this modulator has been given in connection with the Alexanderson alternator. In Figure 3 the microphone is

connected to the grid of a tube. The plate current of this tube varies with the potential of the grid of the tube. This current varies the permeability of the core of the magnetic modulator. The inductance of the coil windings in the aerial circuit varies with the permeability of the core. This changes the tuning of the aerial and the amplitude of the current in the aerial varies. Thus the intensity of the waves in the ether varies with the voice frequency. This method was used some years ago but has not been used since vacuum tubes have come into general use.

327. Grid Modulation. In grid modulated sending sets only one tube is needed. Figure 4 is a grid modulated transmitter which requires very simple apparatus. It has been called a resistance transmitter. The tube is shown connected to a Hartley series coil of a few turns. The coil can be a loop of about three or four feet diameter, two to four turns. The filament is connected to a point near the middle of the loop. A grid condenser is placed in the grid circuit. The microphone is connected to a resistance box, R_1, through a battery of three or four dry cells. The resistance in the box can be changed at will,—50 to 100 ohms will be found to be good. The microphone changes the current through the resistance and thus the potential across R_1. R_1 is connected to the grid of the tube, the potential of the grid is determined by the voice frequency and the oscillating current in the coil is varied in unison with the voice frequency. Figure 5 is a diagram illustrating the action of a tube using grid modulation.

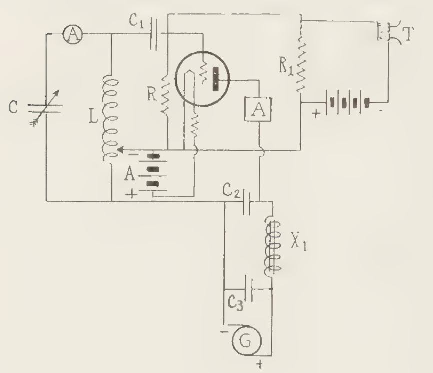


FIGURE 4.

Figure 5 is that of the mutual characteristic of the tube. The irregular line about the lower part of the Y axis represents the potential of the grid as determined by the voice frequency. The amplitude of the oscillating current will be controlled by this frequency. The zigzag line between the X axis and the irregular

boundary represents the oscillating current. It will be noted in the figure that when the modulation is very great there will be times when the current dies out. This is due to the fact that at times the grid is enough negative to make the plate current zero and, of course, this stops the oscillation. One of the drawbacks to grid modulation is the difficulty of preventing distortion.

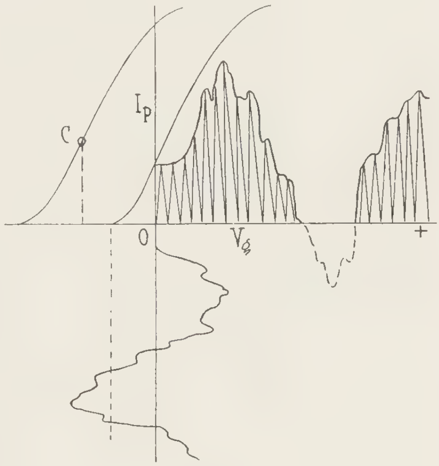


Figure 5.

In Figure 5 the mutual characteristic is represented with the average grid potential at zero. If a high plate potential is used so as to move the curve to the

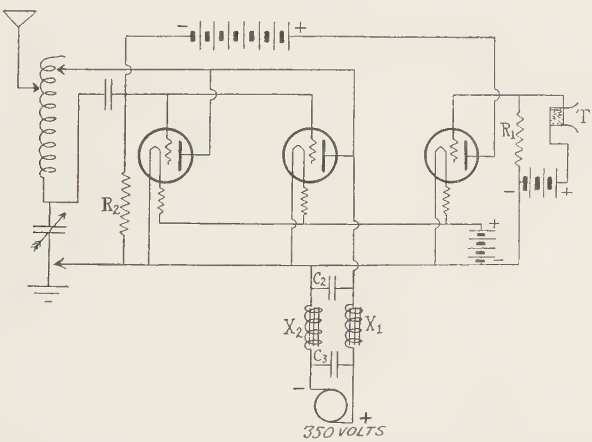


Figure 6.

left and enough C battery or the grid condenser and grid leak are adjusted to place the working point near the middle at *C*, there

will be less distortion provided the variation of the grid potential is not too much. The variation to the right should not be enough to cause a grid current to flow and the variation to the left should not bring the plate current near zero or to the region where the characteristic is a curved line. Figure 6 shows the resistance telephone circuit with two tubes connected to the aerial with the Colpitts circuit. An extra tube is used as an amplifier for voice frequency.

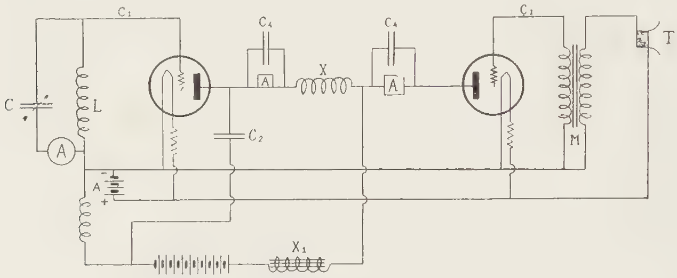


FIGURE 7.

Very few sets use grid modulation, but a set of this kind can be constructed with a rather small amount of apparatus.

328. Plate Modulation. The usual method of modulating a radio phone transmitter is known as Heising plate modulation. In an oscillating tube the radio frequency current depends on the potential of the plate of the oscillating tube. The potential of the plate is made to vary in unison with the voice frequency.

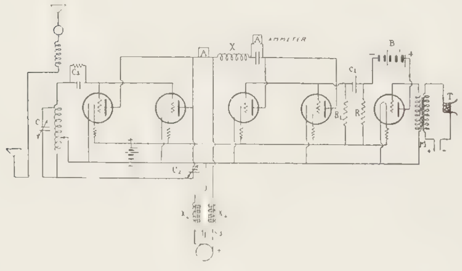


FIGURE 8.

The circuit usually used is that which is known as Heising modulation. The circuit is that in the diagram Figure 7. At least two tubes are used. One tube is known as the oscillating tube and the other is known as the modulation tube. In Figure 8 the oscillating

tubes are connected to a Hartley shunt circuit, and the aerial is connected to this circuit, inductively. The plate current of the two oscillating tubes and of the two modulating tubes flows through a choke coil, X_2, of high inductance. The effect of this choke coil is to keep the current constant. The plate current of the modulating tube is controlled by the grid potential which is coupled inductively to the microphone. When the plate current of the modulating tube is diminished the choke coil tends to keep the current constant and the potential at the plates is increased. Since the modulating tubes are prevented from taking the current, the oscillating tube must take more and thus the value of the oscillating current is increased. The microphone M, is connected to the grid of the modulating tube through the microphone transformer, T. Figure 9 shows a microphone transformer.

FIGURE 9.

A radio frequency choke coil, X, is in the plate circuit of the modulating tube. This choke coil has the proper inductance to keep the radio frequency current out of the modulating tube, but the inductance is so small as to have no effect on the audio frequency. In Figure 8 five tubes are shown,—two oscillating tubes, two modulating tubes and an amplifying tube. It is usual to use the same number of tubes in each group. It is found that due to tube interaction it is impractical to use many more than four tubes in parallel unless special precaution is taken.

When large tubes are used it is necessary to amplify the current from the microphone before the potential is placed on the grid of the modulator. If the tubes are large tubes, perhaps two or three stages of amplification will be needed between the microphone and the modulator tubes.

If in Figure 7 the coils L_1 and L_2 consist of a few turns of wire wound as a loop about four feet in diameter and the tubes are ordinary 201A receiving tubes, a demonstration radio telephone

can be made in this manner which will transmit the most of a mile. A coil of two turns four feet in diameter and a tickler coil of two turns will give frequencies in the amateur band. The tuning condenser is an ordinary variable condenser. For details see "Experimental Radio."

329. Constant Frequency Circuits. As in radio telegraph circuits, it has been found that better results for keeping the station exactly on the desired wave can be had if a low powered oscillator is used as a master oscillator and this frequency is conducted to the power tubes or radiating tubes through a chain of amplifiers. Figure 10 is a constant frequency circuit. The exciter, a small or

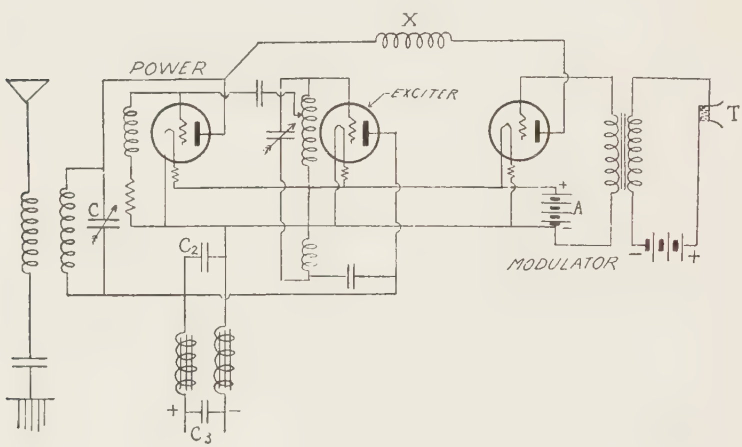


FIGURE 10.

middle sized tube, usually sets the frequency for the power tube. The third tube, in the figure, connected to the microphone is the modulator. Unless the tubes are very small, an amplifier should be used in the microphone circuit.

330. Crystal Controlled Circuits. In modern broadcasting circuits it has been found that it is a great advantage to use crystal controlled circuits. This is a type in which the frequency of the master oscillator is not controlled by the inductance and capacity of the circuits but by a quartz crystal. Such a circuit is diagrammed in Figure 11. The principle of the crystal control is explained in Chapter XXIII.

The application of crystal control will be shown in actual circuits of modern stations.

331. Side Bands. We have explained modulation by saying a modulated wave is one in which the amplitude varies more or less regularly at a frequency that is considerably less than the carrier

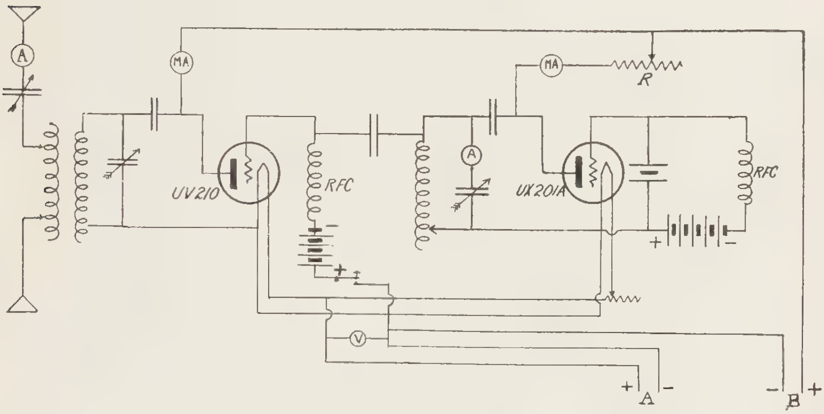


FIGURE 11.

wave frequency. Mathematically it can be shown that this is equivalent to three frequencies, the carrier wave and two frequencies, one equal to the difference of the two frequencies and the other equal to the sum of the two frequencies. Thus if a million cycle wave is modulated with a thousand cycle frequency we will have besides the carrier wave a frequency of one million one thousand cycles, and a frequency of nine hundred and ninety-nine thousand cycles. The 1001000 and the 999000 frequencies are the side bands.

Let $i = I_0 \sin \omega t$ be the equation of the unmodulated carrier wave.

Let $I = I_0' \cos \omega_1 t$ be the equation of the modulating wave. It is remembered that a sine wave is a cosine wave if the origin is changed 90 degrees.

Then the modulated wave

$$i' = (I_0 + I_0' \cos \omega_1 t) \sin \omega t$$

$$i' = I_0 \sin \omega t + I_0' \cos \omega_1 t \sin \omega t$$

$$i' = I_0 \sin \omega t + I_0'/2 \cos \omega_1 t \sin \omega t + I_0/2 \cos \omega_1 t \sin \omega t$$

Adding and subtracting $I_0/2 \cos \omega t \sin w_1 t$ we get

$$i' = I_0 \sin \omega t + I_0/2(\sin \omega t \cos \omega_1 t + \cos \omega t \sin \omega_1 t)$$
$$+ I'/2(\sin \omega t \cos \omega_1 t - \cos \omega t \sin \omega_1 t).$$

Then

$$i' = I_0 \sin \omega t + I_0/2 \sin (\omega + \omega_1)t + I_0/2 \sin (\omega - \omega_1)t.$$

Remembering that $\omega = 2\pi n$, we see that we have two frequencies besides the carrier wave—a sum and a difference frequency.

These two frequencies are known as the side bands.

The Federal Radio Commission has arranged the U. S. broadcast stations in channels which differ by a frequency of 10000 cycles. If a station were modulated with a frequency of 10000 cycles this station would be oscillating at frequencies which would be the frequencies of the two neighboring channels. Or if two stations on neighboring channels were both modulated with a frequency of 6000 cycles, the two stations would overlap 2000 cycles.

Figure 12 illustrates the production of side bands by means of sine waves. Curve *a* represents the carrier wave. Curve *b* represents the modulating frequency. Curve *c* is the modulated wave in which the amplitude of the carrier wave changes periodically. Curves *d*, *e*, and *f*, are the three waves which are mathematically equivalent to the wave *c*. Curves *d* and *f* are the side bands.

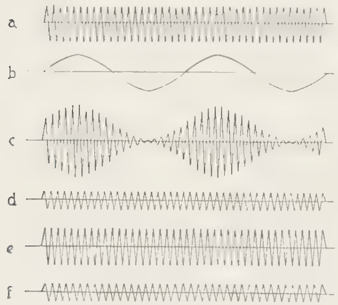


FIGURE 12.

A receiver which is too selective may cut off the side bands. A radio telephone transmitter using long waves does not make a good transmitter because the wave must be very broad in order to transmit the side bands caused by a high pitch sound. A transmitter whose wave is 5000 meters has a frequency of 60,000 cycles. A tone of 5000 frequency gives side bands whose wave lengths are 4600 meters and 5450 meters.

332. Transmitting without Carrier Wave. Figure 13 is a diagram of a transmitter in which the radio frequency is supplied by a generator to the grids of the two tubes. This circuit is called a balanced modulator in the trans-Atlantic transmitter. The high frequency current from the plates of the tubes will run in opposite directions through the two coils, L_1 and L_2. As long as these currents are equal the induced effect in the aerial will be balanced and the aerial current will be zero. When the microphone is in use the potential of the two grids is in opposite phase with respect to the low frequency from the microphone. When the average potential of the top tube is increased the output of this tube is increased, likewise the average potential of the lower tube is diminished and its output is diminished. Thus there will be an induced current in the aerial when the microphone is actuated, and only then. The intensity of this current depends upon the current from the two tubes, and this depends upon the intensity of the sound actuating the microphone.

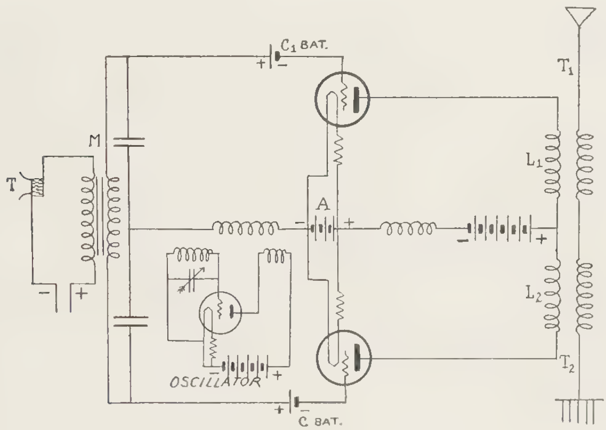


FIGURE 13.

In the aerial there will be nothing to correspond to the first term of the equation showing the three sets of frequency. The term which is absent represents the carrier wave. Thus we have transmission without carrier wave.

The purpose of the carrier wave is to supply energy to the side bands. The audio tones are made by the interference of d and f, Figure 12, with e. So in order to receive these side bands it is necessary to supply a carrier wave at the receiver.

333. Suppression of One Side Band. In Figure 12 the modulated wave, c, is analyzed into three waves—d, the lower side band, e, the carrier wave, and f, the upper side band. In reception with a detector we can explain the action as has been done when we explained detection by means of change of amplitude, or we can reproduce the audio tones by combining the carrier wave with the side bands and produce beats in the same manner as is done in heterodyne reception of C.W. It is not necessary to have both side bands, as the tones can be reproduced from the carrier and one side band. The width of the channel used in the ordinary radio phone is $n+n_1$ and $n-n_1$.

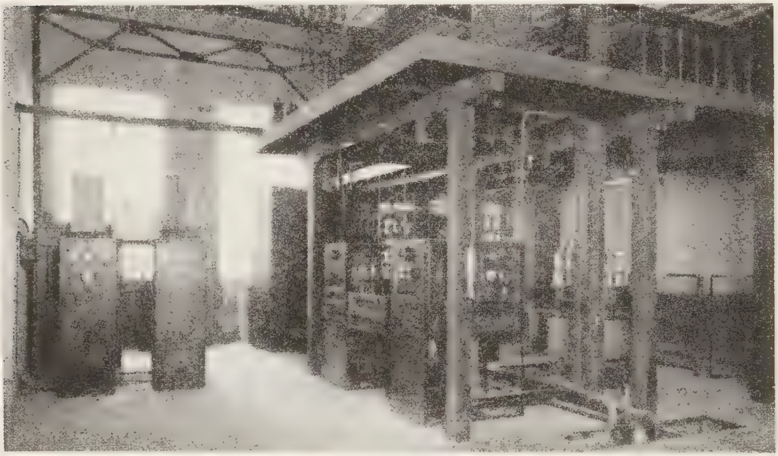


FIGURE 14. Transmitting apparatus for transatlantic radio-telephony, at Rocky Point, Long Island.

If one side band is suppressed by filtering or other means, we have the channel only half as wide, and the interference produced with other stations is diminished. Or, another way of looking at the proposition is to say we have made room for another station, since the channel has been reduced.

Probably the best example of side band suppression is in the trans-Atlantic radio telephone. Figure 14 is the interior of the trans-Atlantic transmitter station.

334. Trans-Atlantic Radio Telephone. In the trans-Atlantic radio phone we have a case where both carrier wave and one side band are removed. Transmission is made with the lower side band only. We start with a transmitter like that in Figure 13, which apparatus we shall call a balanced modulator. The audio frequencies, voice frequencies, transmitted by the apparatus, are from less than 300 to about 3000 cycles. We shall assume a constant frequency of 1000 cycles as representing the voice frequency. The frequencies used in this explanation are, in round numbers, approximately the values in actual use. See Figure 15.

We have an oscillator set at 30 kilocycles and the voice frequency of 1 k.c. feeding into the first balanced modulator. This delivers

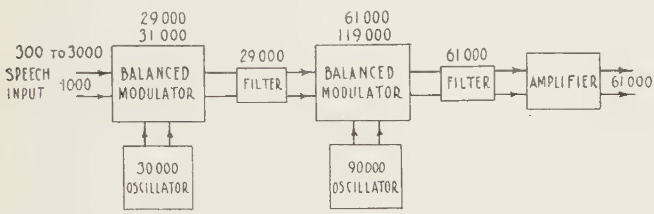


FIGURE 15.

two side bands 29 and 31 k.c. The bands are passed through a filter which suppresses the 31 k.c. band. The 29 k.c. is fed into the second balanced modulator which is also actuated by an oscillator at 90 k.c. The output of this modulator is the two side bands 90 ± 29 k.c. The lower, 61 k.c., is used and the other is filtered out. Sixty-one k.c. is a frequency near 5000 meters and is amplified and transmitted. The actual frequency used in the trans-Atlantic set is 55500 cycles plus speech frequency, making a wave length of about 5400 meters.

Figure 16 is a diagrammatic scheme of the amplifiers after the second filter. The amplification is in five stages beginning with one five watt tube and ending with 20, 7.5 K.W. tubes in parallel. The advantage of this method of transmission is that all the energy is in the side band and none is in the carrier wave. Thus,

the width of the channel is diminished to a minimum. This last is a big item in long waves. With a voice frequency of 3000, the channel occupied is from 5100 to 5400 meters.

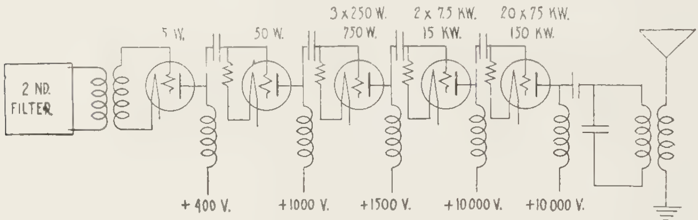
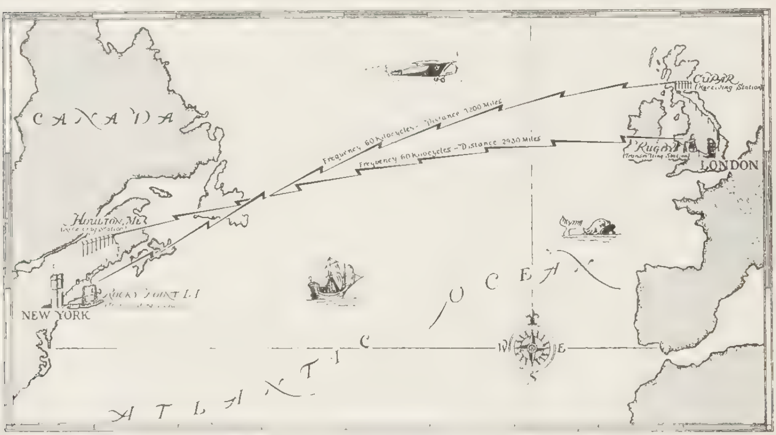


FIGURE 16.

In reception it is necessary to supply the carrier wave, 55500 cycles, at the receiver. It is interesting to note that the carrier wave 55500 cycles which is "suppressed" is not even generated at the transmitting station. If the carrier generated at the receiver is



Schematic of transatlantic radio telephone circuits

FIGURE 17.

too close to the side band the notes are low. If they are too far away the notes are high. In either case, the articulation is not good. For good results the variation of frequency of the carrier wave should not be more than 20 cycles. Figure 17 shows a pictorial figure of radio telephone transmission and reception across the Atlantic.

335. Complete Modulation. Figure 18 is a figure representing a carrier wave modulated by a sine curve. The percent of modulation is $100(m-c)/c$ where c is the amplitude of the carrier wave and m is the maximum amplitude of the modulated wave. If m is equal to $2c$, then the modulation is 100%. This means that the amplitude of the carrier wave at a minimum point is zero and the wave is said to be completely modulated.

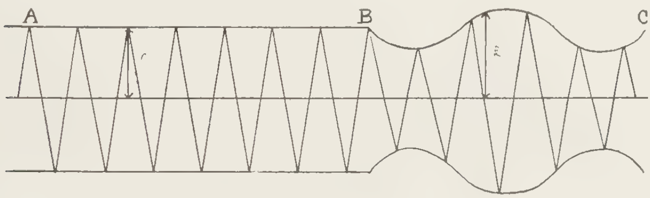


FIGURE 18.

The amount of power delivered to the antenna in a radio telephone depends on the degree of modulation. If 100% represents the power delivered to the antenna by the unmodulated carrier wave the energy delivered when completely modulated is 250% and the maximum peak energy, instantaneous value, is 400%.

The useful energy is in the modulation or side bands, thus the efficiency of a transmitter depends upon the percent of modulation.

The better stations are adjusted so as to operate at a point corresponding to complete modulation for the intense notes.

336. Large Transmitters. In the early days of radio broadcasting the transmitter consisted of two tubes, or two groups of tubes, the oscillators and the modulators, connected with Heising modulation. Usually there was a tube or two used as audio amplifiers for the microphone circuit. In order to maintain constant frequency, master oscillator circuits or crystal controlled circuits were introduced. These, as has been shown, consist of a train of tubes connected as radio frequency amplifiers. So we have two trains of amplifiers,—the audio feeding into the modulator tube or tubes, and the radio frequency from the master oscillator feeding into the oscillator tube.

It is possible to have two small tubes, one as an oscillator and the other as a modulator, like the connection in Figure 7, and then

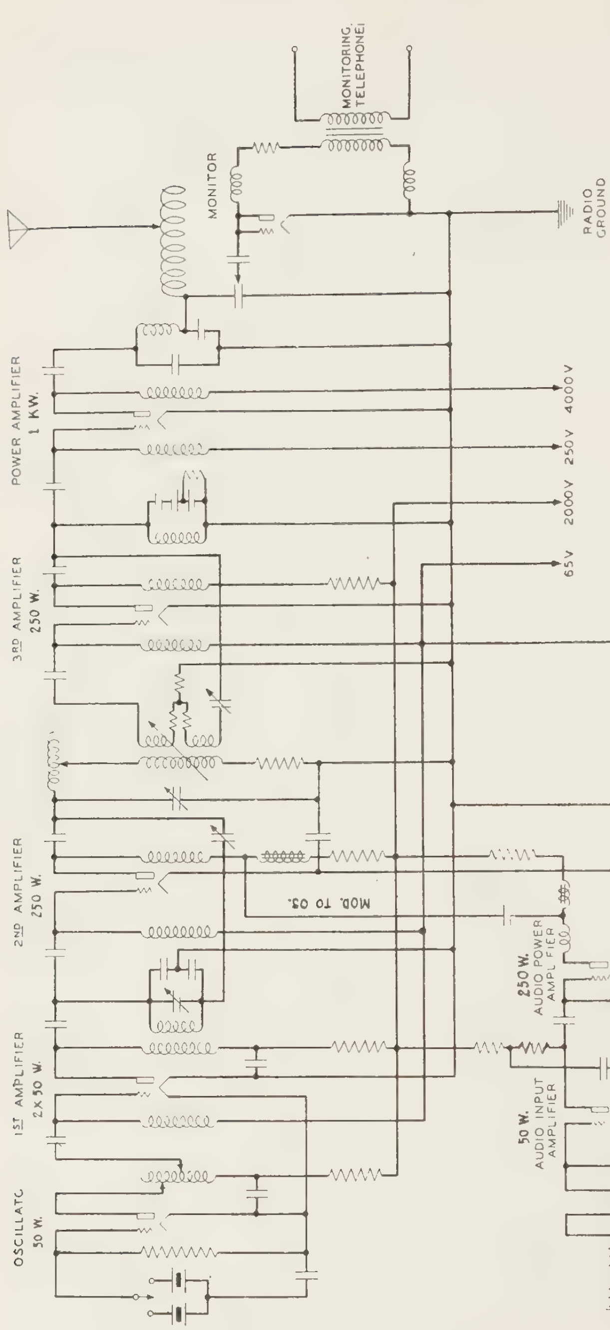


FIGURE 19. Diagram of the Western Electric one kilowatt broadcast transmitter.

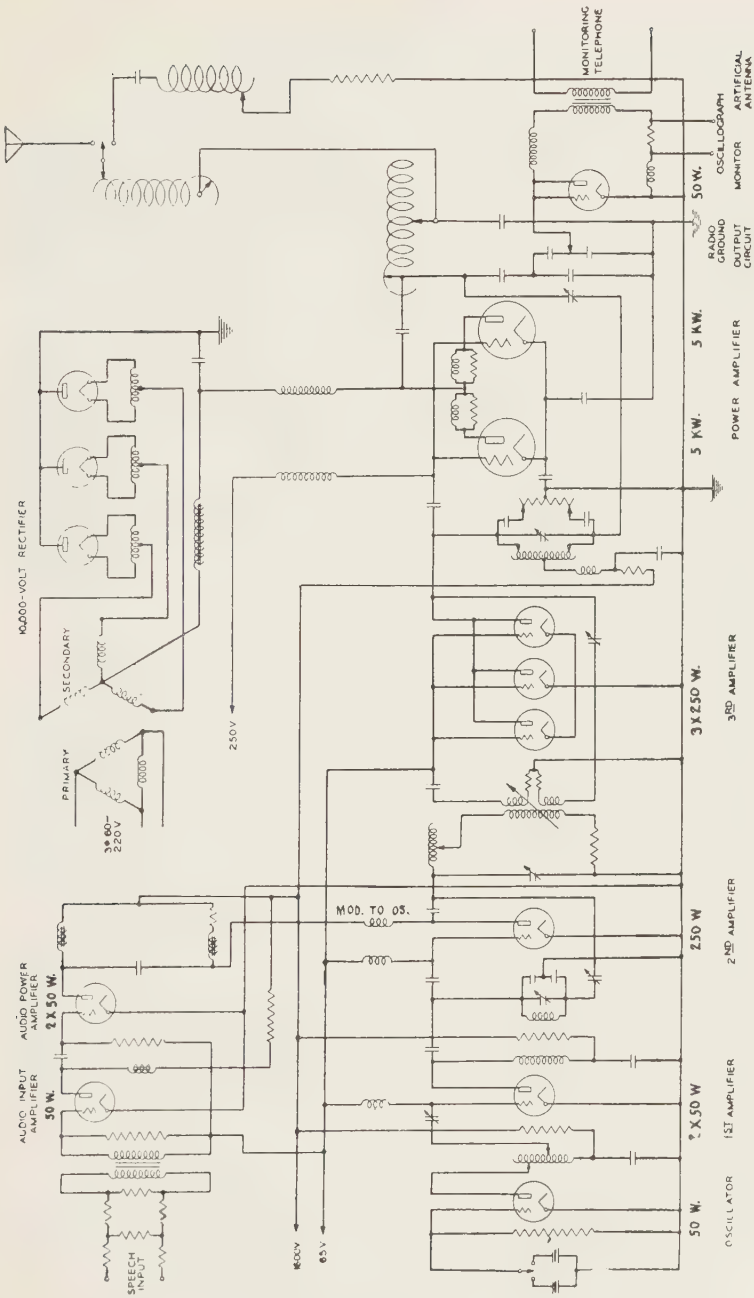


FIGURE 20. Diagram of the Western Electric five kilowatt broadcast transmitter.

have a train of radio frequency amplifiers feeding into a power oscillator. Such an amplifier will be one which amplifies modulated

FIGURE 21. Fifty-kilowatt radio broadcast transmitter at 3XN.

FIGURE 22. Station 3XN, Bell Telephone Laboratories, at Whippany, N. J.

radio frequency. This method is used in the larger stations, since it is a saving of power. This will be seen by following the diagrams

of Figures 19 and 20. These diagrams are simplified diagrams of standard stations of the Western Electric Company. It is interesting in connection with these diagrams to note the speech amplifiers and the rectifiers.

Figure 21 is a view of the fifty K.W. broadcast transmitter at 3XN.

Figure 22 shows the aerial at 3XN, and Figure 23 the second power amplifier in the same station. Figure 24 shows condenser microphones in the forms in which they are used in broadcasting stations.

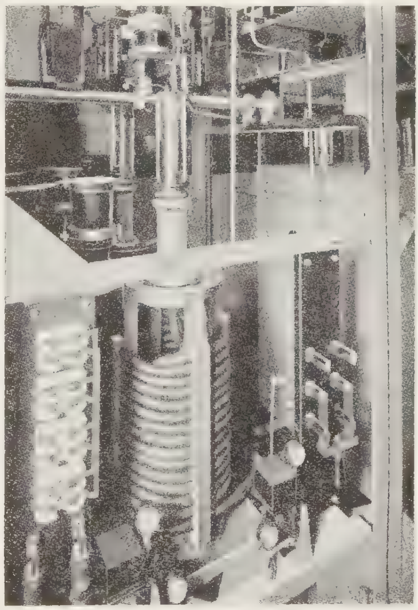


FIGURE 23. The second power Amplifier Tube Unit of the 50 Kw installation at 3 XN.

337. Chain Circuits. A chain circuit is one in which a number of broadcasting stations transmit the same program at the same time. The program is given in a studio, picked up on the microphone and amplified and placed on the long distance line. This may go to a station direct, where it is amplified and placed on the transmitter. It may go to a second amplifier one or two hundred miles away, where it is amplified on a repeater amplifier. At any of these points two or more branch lines may pick up the program. At distant points other amplifiers may transmit to other branch lines.

The amount of amplification at any amplifier is adjusted so the intensity of the signal does not fall below a certain level at the far end. The intensity of the signals is always kept above the line noises. There are always certain line disturbances due to thermal junction effects, and other electrical disturbances on the lines.

The long distance lines are all loaded to transmit all frequencies between certain limits with equal attenuation. On an ordinary telephone line the low frequencies are transmitted better than the high frequencies. If the line is very long, 100 miles, say, the listener at the far end will hear the low notes louder than the high notes. To overcome this the line is loaded with equalizers. Figure 25 is a diagram of an equalizer. This will be seen to be a case of a parallel resonant circuit in series with a resistance. If the resonant circuit is adjusted for high frequency the impedance for the low notes will be the resistance alone. The impedance of the resonant circuit will increase with frequency. Thus, by proper adjustment, the attenuation of all frequencies can be made the same. This loading coil is a shunt across the lines. It uses up the energy of the low notes so that the intensity of the low notes is the same as that of the higher notes. A loading coil therefore absorbs energy although it improves quality. The average attenuation or waste of energy on the line is greater with the equalizers than without. There must be more amplification to make up.

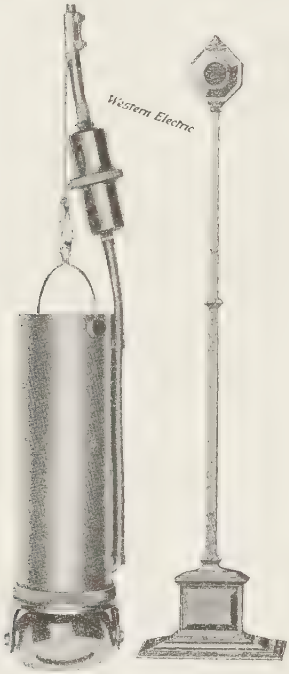


FIGURE 24. Condenser Microphones used in broadcasting.

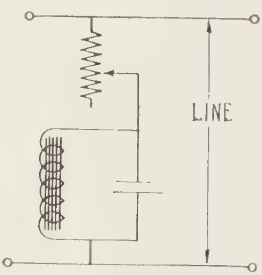


FIGURE 25.

The ordinary telephone lines are loaded for transmission from about 300 to 3000 cycles. Lines for broadcasting transmission

must be equalized for frequencies from 100 or less to at least 5000 for good transmission. If an ordinary line is used the quality of the music transmitted is poor.

338. Radio Chains. It is possible to transmit to a repeater transmitter using radio waves. Usually short waves are used. Due to fading and other factors which cannot be controlled, this method of "hook up" has been discarded. The radio "hook up" and the radio phone does not compete with the wire line except where the cost of wire lines is excessive.

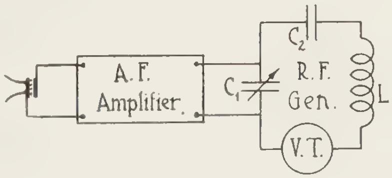


FIGURE 26.

339. Frequency Modulation. The usual Heising modulation is essentially an intensity method of modulation. This has been shown to produce side bands or frequencies which differ from the carrier frequency in unison with voice frequency. Thus, if the frequency of the carrier wave can be made to vary in unison with the voice frequency, we have a method of modulation.

In Figure 26 we have a microphone connected across a variable condenser which is in the circuit of an oscillating tube. If this condenser is one in which the plates move due to the static force between the charges we have a condenser whose capacity will vary in unison with the voice frequency, and the frequency of the oscillating tube will vary in the same manner.

CHAPTER XXV

RECEIVERS

340. Early Receivers. In Hertz's original experiments an open spark gap, Figure 1, was used as a receiver. In his early receivers, Marconi used the coherer as a detector for the waves. The coherer consisted of two metal plates placed in either end of a glass tube with metallic filings, iron and other metal, placed between the two plates. The resistance of these loosely packed filings was very high. The current from the wave broke down this resistance so that a battery of a few volts caused a large current to flow. By placing a

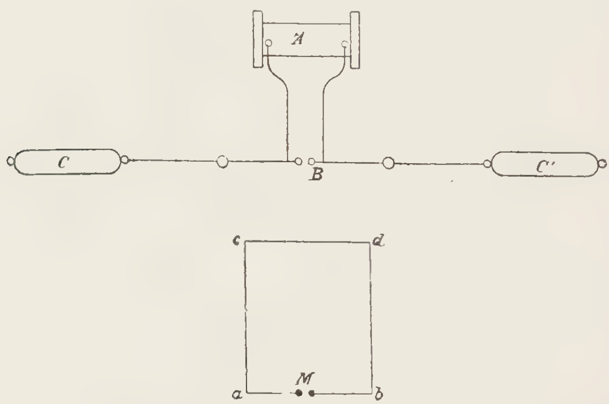
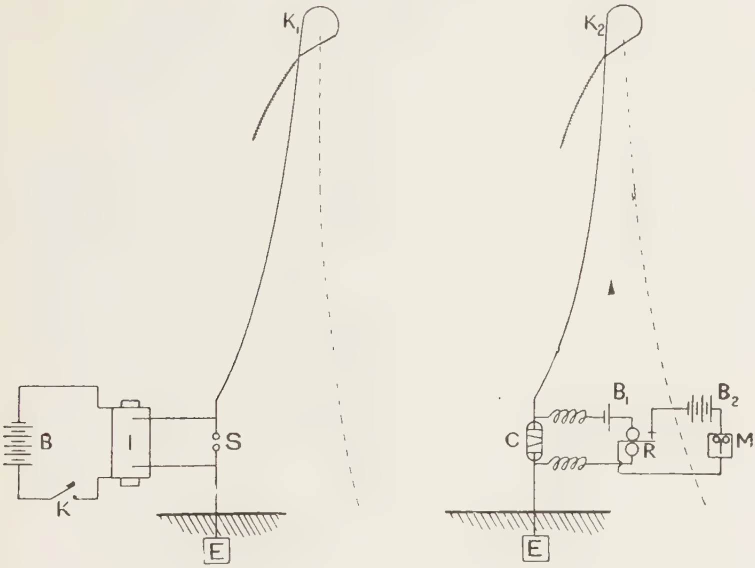


FIGURE 1. Hertz's original receiver and transmitter. The signals were received when a small spark appeared at M.

bell or sounder in series with the coherer and the battery the bell was caused to ring when the wave was received. By tapping the coherer the filings were jarred and the resistance restored, causing the bell to cease ringing.

Figure 2 shows one of the earliest receivers. The transmitter used is also shown. It is seen to be a primitive spark transmitter. There was no tuning except that the receiving circuit was made as near like the transmitting circuit as possible. The length of the aerials being the same, the two circuits were tuned. These aerials were supported by kites.

341. Crystal Receivers. Crystal receivers or detectors were



Transmitting station. *Receiving station.*

FIGURE 2. Marconis' Apparatus for Wireless Telegraphy in 1896. *B*, battery *I*, induction coil; *S*, spark balls; *K*, sending key; *E*, earth plate; K_1, K_2, kites upholding aerial wires; *C*, Coherer; *R*, relay; *M*, Morse printing instrument; B_1, B_2, batteries. From Fleming, "Electric Wave Telegraphy."

introduced in 1906 and became the standard detector until the introduction of vacuum tubes. See Chapter IX, Detectors.

It is imposible to enumerate all the different types of receiving circuits. All receiving circuits can be classed in some half dozen types. All the various wave meter, oscillating, and sending circuits can be used as receivers with a detector.

The most simple receiver is the crystal detector receiver. The most simple one of this type is a crystal and a telephone placed in an aerial circuit, Figure 3. To use this circuit the intensity of the signals must be very strong.

Placing a variable inductance or a variable condenser around the telephone and crystal we have a means of tuning the circuit. With a double slide tuner, Figure 4,

FIGURE 3.

we have a means of tuning both the aerial circuit and the crystal circuit. The maximum response is obtained when the aerial circuit, the aerial and the portion of the coil included between the ground and aerial tap, as well as the portion of the coil between the upper portion and the second tap, is tuned to the signal.

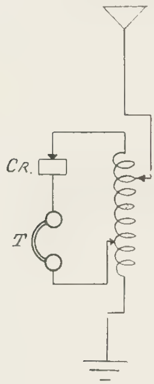


FIGURE 4.

An oat meal box with 70 turns of wire—40 turns from aerial connection, then 15 taps with 2 turns between taps make a good receiver of this type.

The loose coupler circuit, Figure 1, Chapter IX is the best crystal circuit. The aerial is tuned by the sliding tap and the secondary is tuned by means of the variable condenser. If the coupling is loose and the resistance of the secondary circuit is small this circuit is selective. Unless a great deal of care is used in the construction of a good low resistance aerial and ground connection the range with crystal detectors is not very great. 25 to 50 miles is good.

342. Tube Receivers. If an electron tube is substituted for the crystal detector in the above circuits the range is greatly increased. With a tube in the above circuits we have plain detector circuits, not regenerative.

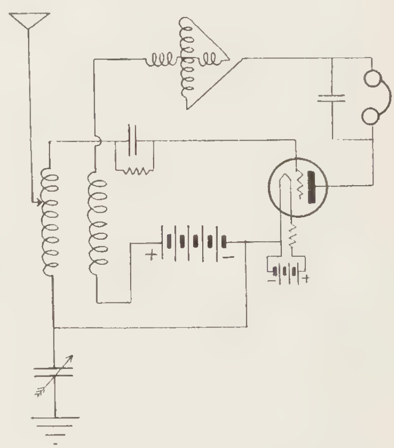


FIGURE 5.

Figure 5 is a regenerative circuit which has become very popular. It is very easy to tune. It has the disadvantage that the grid of the tube is connected to the aerial circuit and any local disturbance such as induction hum from transformers will be communicated directly to the tube. The resistance of the aerial will cause the wave to be "broad" and the selectivity of the circuit will be poor. One redeeming feature is the tuned plate circuit. This is tuned by means of the variometer in the plate circuit.

Figure 6 is another two coil regenerative circuit. The loose coupler of Figure 1 Chapter IX can be used in this manner. This circuit is fairly selective but is likely to be noisy. Two coil circuits are a nuisance to the community. When the tube oscillates the aerial becomes a transmitting station. Since the aerial is conductively coupled to the circuit there is no way of reducing the energy radiated by loosening the coupling.

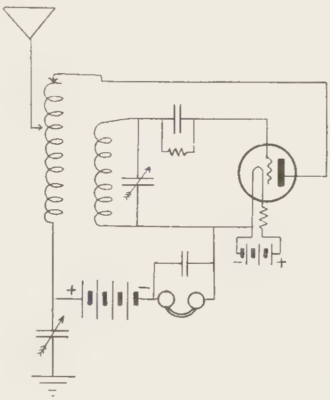


FIGURE 6.

The three coil regenerative circuits are the most selective and most free from local disturbance. Figure 7 is a three coil circuit which is usually given as the typical regenerative circuit. The three coils should be mounted so that the coupling between coils can be changed. The aerial circuit is tuned either with a condenser or by means of taps on the coil. The secondary circuit is tuned by means of a variable condenser.

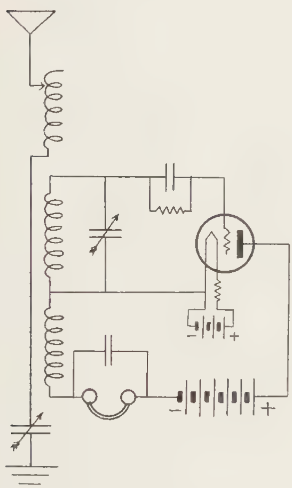


FIGURE 7.

343. Coil for Broadcast Receiving. The construction of coils for the reception of 200 to 600 meters is described in the following.

Procure 100 feet of number 24 cotton covered copper wire. Wind this wire on a rolled oats box or any paper tube whose diameter is about four inches. Make three coils of 25 turns of wire in each coil. Wind the coils one layer deep. Leave a space of about one-half inch between each coil. Each coil will have two terminals—six terminals in all. Number the terminals 1, 2, · · · , 6, numbering from left to right. Connect No. 1 to the ground, No. 2

to the aerial. Connect No. 3 to the grid terminal of the tube, No. 4, to the negative filament of the tube. Connect one of the variable condensers to terminals No. 3 and 4 also. Connect No. 5 to the negative filament of the tube, No. 6 to one terminal of the phone, the other terminal of the phone to the negative terminal of the B battery and the positive terminal of the B battery to the plate terminal of the tube. The by-pass condenser should be connected around the phone terminals and the grid condenser placed in series with the grid circuit. The second variable condenser is placed in series or in parallel with the coil connected to the aerial. This makes a good regenerative circuit. All high power phone stations in a radius of 1000 miles can be heard with this outfit, on good nights.

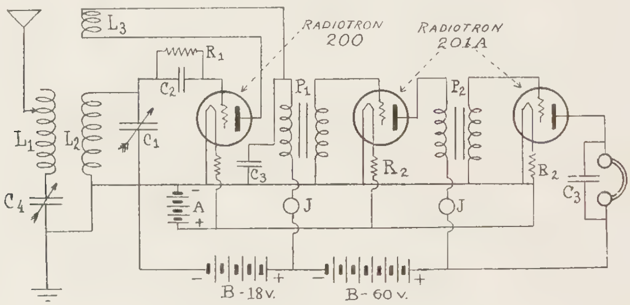


FIGURE 8.

This coil may be made into a loose coupler by cutting the coils apart and fastening the coil to wooden blocks. Fasten the middle coil rigidly to a wooden support and by means of hinges fasten the other two on each side of the first so that they will swing like the leaves of a book from a position parallel to the middle coil to a position at right angles to the middle coil. Mount so that when the coils are closed they occupy the same relative position that they did before they were cut apart. Six binding posts, one for each terminal, will add to the convenience of this coil. The wave length range of this receiver using a 43 plate condenser is from 200 to 600 meters.

Adding two or three stages of audio amplification we have the circuit of Figure 8 which is a very good cheap receiver.

Many other simple receivers might be given but they can be shown to be a particular case of one or two type forms. Compare vacuum tube circuits Figure 8, Chapter XIV, where it is shown that circuits can be transformed into standard forms.

344. Modern Receivers. In previous sections the subjects of the tube used as a detector and amplifiers have been discussed. In practice the receiver and amplifier are so closely associated that it is hard to think of one without the other. All modern receivers consist of a detector and some sort of an amplifier. Even with the single tube receiver, the tube acts as both a detector and an amplifier. The tube itself not only is an amplifier but as a usual thing the circuit is some sort of a regenerative circuit, which also amplifies. The receiver as used usually consists of a radio frequency amplifier, a detector, and a stage or two of audio frequency amplification.

345. Radio Frequency Amplifiers. There are two general types of radio amplifiers,—tuned and untuned. In the untuned amplifiers the receiver proper which is a tuned circuit coupled to the aerial, is connected to the grid and filament of the first tube. The simple wave meter circuit is generally used. The plate circuit of the first tube is coupled to the grid circuit of the second tube with a transformer which is untuned. The transformer as connected to the tubes has a natural frequency which is not far removed from the frequency which is received.

The number of turns in the transformer, of course, depends on the frequency range which is desired. The ratio of the transformer is near unity. The transformer is usually made of small wire and the two coils are very closely coupled. The coupling and resistance makes the peak of the wave, or resonance curve, very broad so that the amplifier is in tune for a large band of frequencies.

This method of keeping the tubes from oscillating has been called a "losser" method. The energy is dissipated, as heat in the resistance, to the point that the tube can not oscillate. Some of the "losser" methods resorted to in the early days, and to some extent at the present time, are high resistance coils, a positive potential on the grid of the tube, and the introduction of eddy current losses. Some of the untuned radio frequency coils are made of resistance wire. All are made of fine copper wire. A potentiometer between the filament terminals makes the grid potential

adjustable and the plate current is increased, thus increasing the *IR* drop through resistance of the coil until losses are so great that the tube ceases to oscillate. Resistance is sometimes inserted in the grid circuit. Sometimes the coil is mounted close to a sheet of aluminum in which there are eddy currents induced. This increases the apparent resistance of the coil. A few years ago it was common to see sets advertised for which one of the talking points was low loss coils. These coils were mounted on the condensers close to the heavy aluminum end plate. Untuned radio frequency amplification is not used to any extent now except in the intermediate frequency stages of the superheterodyne. The diagram, Figure 9, illustrates an untuned radio frequency amplifier in the first two stages.

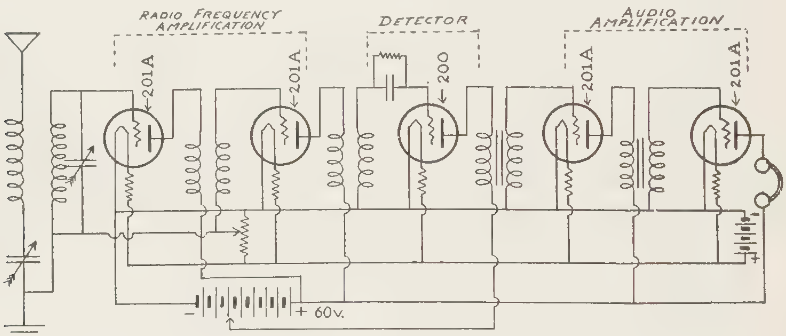


FIGURE 9. Circuit for radio frequency amplification and two stages of audio amplification.

In the tuned radio frequency amplifier the transformer is usually tuned with a condenser. If a condenser is placed across the secondary of the coupling transformer in Figure 9, the diagram for a tuned radio frequency amplifier will be complete. All radio frequency amplification must be before detection.

The advantage of radio frequency amplification is that the detector output depends on the square of the potential of the signal. Amplification before the detection tube is, therefore, much more effective. See sections on Detection, Chapters IX and XII. However, it is possible to get the signal so intense as to overload the detector tube and thus produce distortion. The signal should not be so intense as to use more of the characteristic than the curved portion.

One of the difficulties of the radio frequency amplifier is that there is danger of one or more of the tubes oscillating due to the capacity feed back through the tube. See Chapter XIV on oscillators.

The screen grid tube is designed to screen the plate of the tube from capacity effect. This tube has been used with good success

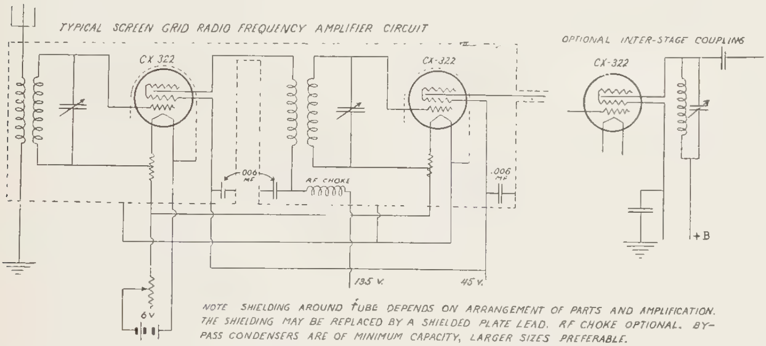


FIGURE 10.

in radio frequency amplification. Figure 10 is a diagram of a set using screen grid tube in radio frequency amplification.

All the "losser" methods make the tuning broad so that the set is not selective and, as a usual thing, the adjustment is such that the output of the B battery is great thus shortening its life.

346. Neutrodyne Set. One of the best radio frequency amplifiers is the Neutrodyne set. This was the first attempt to neutralize the capacity of the tube and thus prevent oscillation. The principle of the set is made clear by the following, which can be used as a method of measuring the amplification of a transformer. In Figure 11 P and S are the primary and the secondary of the transformer whose amplification is to be measured. C_1 and C_2 are two variable radio con-

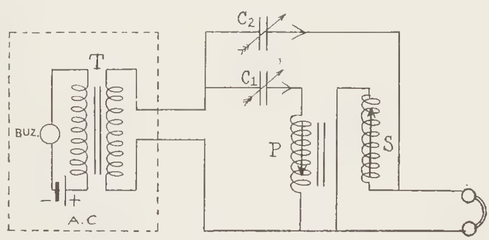


FIGURE 11.

densers. The connections of the coils must be reversed as in the diagram. The E.M.F. in the secondary due to the current from the condenser, C_1, must be in the same direction as that from the condenser, C_2. Then when the condensers are so adjusted that there is a minimum sound in the telephone, the condenser, C_2 neutralizes the effect of the condenser C_1. When this is true the ratio of the condensers is the same as the ratio of the coils and the amplification constant, A, is C_1/C_2.

Since the capacity of the condensers is small, the impedance in the two coil circuits is all due to the condensers, and I_1 is proportional to C_1 and I_2 is proportional to C_2. This can be seen from the equation,

$$I = \frac{E}{\sqrt{R^2+(L\omega-1/C\omega)^2}} = CE\omega, \text{ when } C \text{ is small.}$$

Since there is no current through the telephone,

$$M dI_1/dt = L dI_2/dt \quad \text{or} \quad MI_1 = LI_2.$$

Since M is proportional to $n_1 n_2$ and L is proportional to $n_2{}^2$, $n_1 I_1 = n_2 I_2$.

Then $n_2/n_1 = I_1/I_2 = C_1/C_2 = A$, the amplification ratio of the two coils.

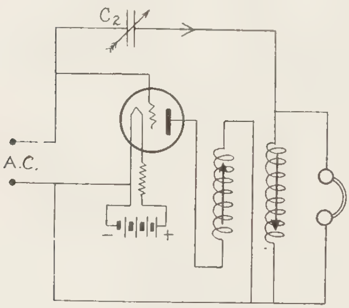


FIGURE 12.

If C_1 and C_2 are variable condensers, semi-circular plates, which are exactly alike (same make) then the readings of the dials can be substituted for the value of the capacities.

If C_1, Figure 12, is the capacity of a tube, then the neutralizing condenser, C_2 causes the coils to neutralize the capacity of the tube. In Chapter XIV we saw that the capacity acting as a feed back in the tube caused the tube caused the tube to oscillate in certain cases. Since the capacity of the tube is neutralized the tube will not oscillate. In a Neutrodyne set the ratio of secondary to primary is about 5 to 1, and the capacity, C_2 must be about 1/5 the capacity of

the tube. It is rather difficult to get a condenser of such small capacity, and it is customary to connect the neutralizing condenser to a tap and use about 1/5 of the secondary of the coil. In some circuits a third coil is placed on the transformer and this coil is used with the primary coil in neutralizing the capacities. Figure 13 is a diagram of a three tube Neutrodyne set. There are two tubes of radio frequency amplification as well as a detector tube and usually two more tubes used as audio amplifiers.

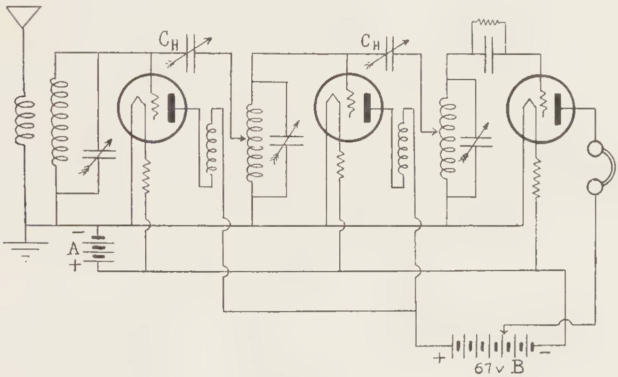


FIGURE 13.

347. Heterodyne Amplification. Another kind of radio frequency amplification is heterodyne amplification. The super-heterodyne is of this type. This makes use of radio amplification but at a rather low frequency. In the section on oscillators we saw that the capacity feed back was more effective as the frequency increased. At comparatively low radio frequencies there is not so much difficulty with the tube oscillating, and it is easier to operate radio amplifiers. In the heterodyne the signal is received on a circuit very much the same as an ordinary receiver. Some receivers use regenerative circuits. Coupled to this circuit is a second tube which is connected to an oscillating circuit. The frequency of the oscillation is above or below the frequency of the signal. The beat note between these circuits is received by a circuit tuned to the beat frequency. This is followed by two or three stages of untuned amplification, the peak frequency of these coils being the frequency of the beat note. After amplification the signal passes through a second detector and usually a stage

or two of audio amplification. Figure 14 is a diagram of a super-heterodyne. To illustrate, suppose the signal is on 500 meters or 600 kilocycles. Suppose the radio frequency amplifier is tuned for 100 kilocycles. Then, if the oscillator is tuned to 600 meters or 500 kilocycles, the beat note is 100 thousand cycles. If the signal is on 300 meters or 1000 kilocycles and the oscillator is set for 333 meters or 900 kilocycles, the beat note is again 100 kilocycles and will pass through the amplifier. The radio frequency amplification is on 100 kilocycles or 3000 meters and on this long wave the tube capacity does not interfere. Very weak signals can be received in this manner. Coil aerials can be used with success. Figure 22 is a modern super-heterodyne.

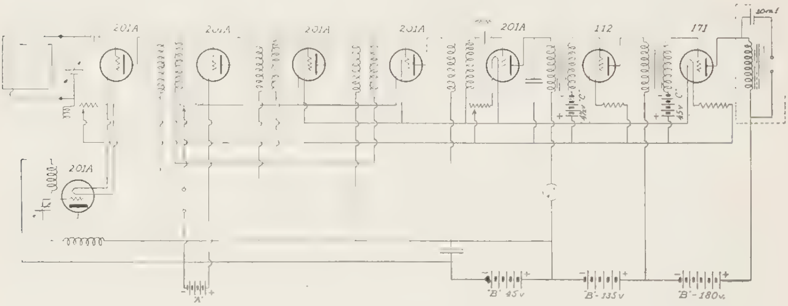


FIGURE 14.

348. Regenerative Amplification. The regenerative receiver is perhaps one of the most popular receivers. Regeneration has been treated to some extent in Chapters IX and XII. The single tube receiver is one of the most efficient receivers made when the simplicity of the circuit is considered. The trouble with this receiver when no amplifier is used is the temptation on the part of the operator to let the receiver oscillate and thus become a small sending station producing interference with other receivers in the neighborhood. This disturbance is known to have been transmitted a mile or two with intensity enough to interfere with reception.

A regenerative tube is usually equal to two or three stages of tuned radio frequency amplification. Thus, as far as amplification is concerned, its efficiency is very high.

If a regenerative tube is used, it should be used with a loud

speaker and an amplifier whose amplification is great enough to make so much noise when the tube starts to oscillate that the operator will stop it immediately.

Figure 8 is a diagram of a regenerative receiver and three stages of audio coil amplification. This will give very good results in the hands of most operators. In this the aerial circuit is tuned by means of the series condenser. A loading coil should be placed in series with the aerial to increase the wave length of the aerial so that it can be tuned to all bands of frequencies.

349. Reflex Amplification. This method of coupling combines radio and audio amplification. It is popularly said to use the tubes twice. Figure 15 is a circuit in which the radio frequency

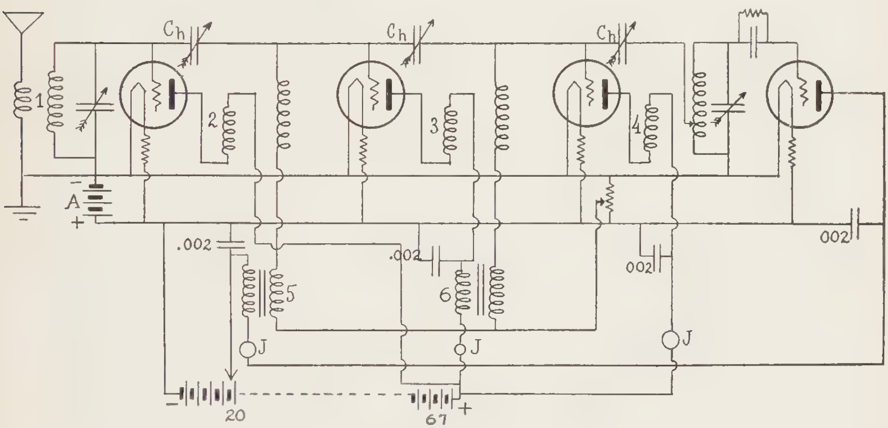


FIGURE 15.

amplification is both tuned and untuned. The tube capacities have been balanced by the neutrodyne principle. After the signal has passed through three stages of radio frequency to the fourth tube, the detector tube, two of the first tubes are used again for audio amplification. The radio frequency signals are bypassed around the audio coils by means of fixed radio condensers. The audio signals pass through the radio coils without any obstruction.

It is customary to depend on the capacity of the audio coil to pass the radio frequency through the secondary of the transformer. Fixed condensers may be placed around the secondary

of the audio coil as well as around the primary. These condensers may throw the secondary in resonance with some high audio frequency.

As a general thing, the amplification obtained with a reflex set is not the same as in a set where the tubes are used only once. With a four tube set reflexed as in the figure, the amplification is little more than that obtained in an ordinary four tube set.

Reflexing broadens the tuning, rendering the set not so selective.

350. Short Wave Receivers. Short wave receivers are very much like receivers for longer waves. They differ in many ways according to the caprice of the builder. Most people interested in short waves build their own apparatus. During the last year or two due to the interest in long distance, short wave broadcasting, a few short wave receivers have been advertised.

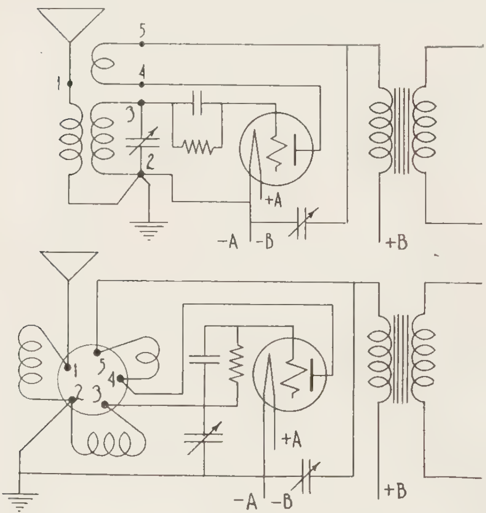


FIGURE 16.

It, of course, is understood that the receiver for modulated code is in no way different from the receiver for broadcast or voice reception. For C.W. code it is necessary to have the receiving tube oscillating.

Super-heterodyne receivers can be used for short waves. It is necessary to change the number of turns of the receiving coil and the oscillating coil. Super-heterodyne receivers with plug in coils have been devised so as to convert from broadcast wave receivers to short wave receivers with little trouble.

Most wave receivers are regenerative receivers in which the regeneration is controlled by means of a variable condenser in the place of the bypass or blocking condenser. By controlling the regeneration the receiver can be used for short wave radio phone reception with the circuit as a regenerative circuit, or C.W. code can be received when regeneration is increased to the point of oscillation.

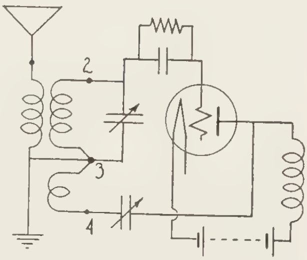


FIGURE 17.

Most circuits are essentially the same as that of Figure 8. The coils have fewer turns and the tuning condenser is usually made with few plates. By removing the aerial condenser, C_4, or by placing it above the coil, L_1, the three coils can be connected to the set with five contacts. The coils can be wound on a form which has five prongs fitting into a five prong tube socket. Figure 16 illustrates the connections.

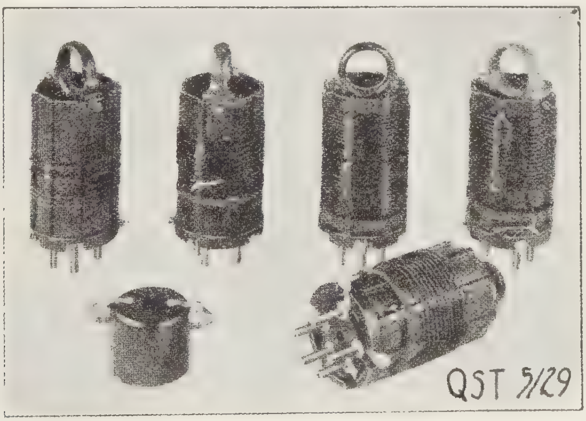


FIGURE 18. A few plug-in coils and a plug-in R. F. Choke. Q. S. T. p. 16. May 1929.

If the circuit is wound as a shunt feed back circuit the coils can be wound on a form made from an old four prong tube base. Figure 17 illustrates the connections. These forms may be wound

with coils of suitable number of turns so as to receive various amateur bands. Figures 18 and 19 are pictures of plug-in coils.

Although there is no fundamental difference between receivers for code and those for use for radio phone, there may be a difference between the audio coils used in the amplifiers. For radio phone receiving we wish transformers which give the same amplification at all audio frequencies. In code reception we want a transformer which will give the greatest amplification in the neighborhood of

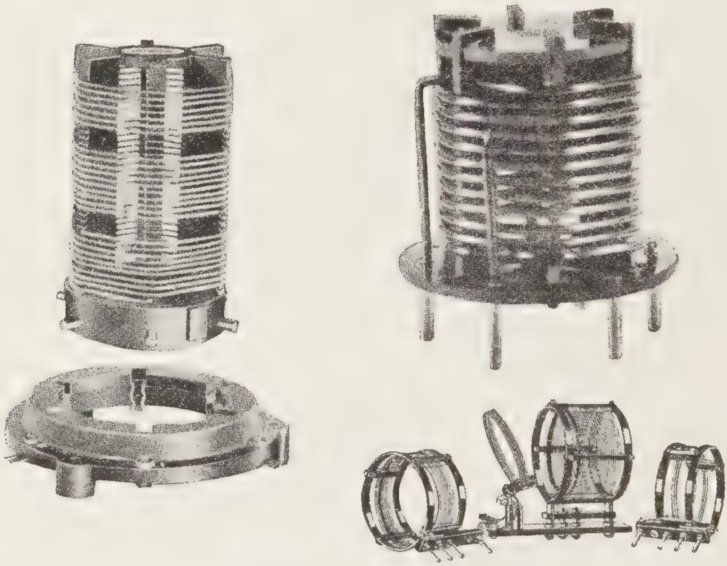


FIGURE 19. Plug-in coils for receivers.

800 or 1000 cycles. This is the tone which can be heard through static the best so the frequency of the oscillator is usually set to give that tone. The transformer should amplify selectively at that frequency.

It is claimed that a UX112 tube makes a good detector for short wave receivers. Short wave sets with audio amplification tend to howl at times. A resistance of 25000 to 100000 ohms placed across the secondary of the audio transformers will usually quiet the set. Figure 20 is a short wave super-heterodyne receiver. Figure 21 is a diagram of the set. For details see Q.S.T., page 9, March 1919.

351. Volume Control. Figure 22 shows a diagram of the connections of the Radiola No. 64 receiving set. This set has a complete lamp socket power unit which furnishes A, B, and C battery potentials. Of course, it is single control. The loud speaker-field coil is one of the filter coils in the smoothing filter. All the tubes are 227 A.C. tubes. The detector is a plate current rectifier. One of the features of this set is a volume control which is diagrammed in simplified form in Figure 23.

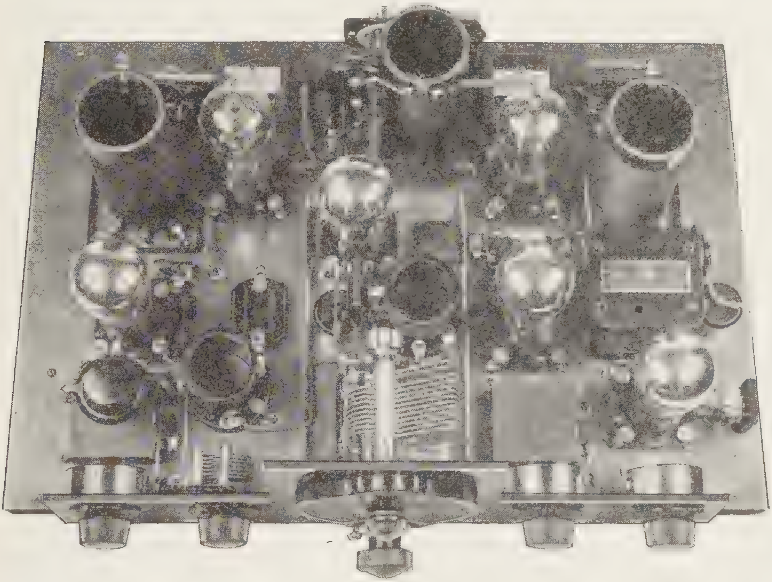


FIGURE 20.

The volume control tube is actuated by the same potential as that of the detector tube. The control tube is in a certain sense a vacuum tube voltmeter. A strong signal causes a large plate current in the control tube. This current flows through a resistance of 100,000 ohms. This causes the potential of the plate to drop. The grids of the radio and audio amplifying tubes are connected to the plate of the volume control. The negative potential on the grids slides the point of action of the amplifiers down to a less steep part on the curves so the amplification is not so great. In this manner the amplification depends inversely on the intensity of the signal.

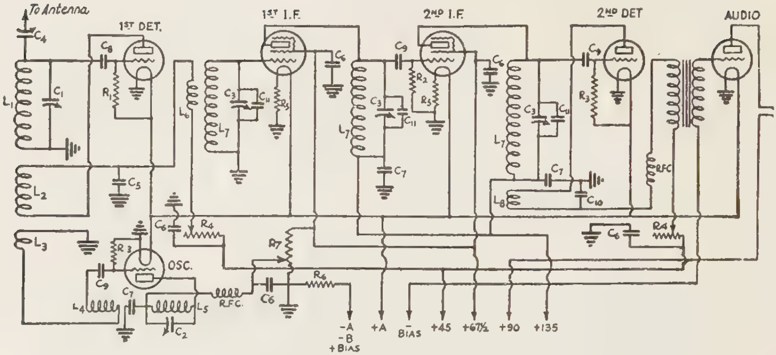


FIGURE 21. The complete wiring of the Super-Heterodyne.

C1—"13-plate" Pilot midget first-detector tuning condenser with 4 plates removed. It is shunted by an external variable of 350 μμfds. for broadcast-band work.
C2—27-plate National Equitune condenser with stator divided (see text).
C3—23-plate Pilot midget intermediate-frequency tuning condensers.
C4—5 plate Pilot midget antenna coupling condenser.
C5—250-μμfd. Sangamo fixed condenser.
C6—1-μfd. Acme Parvolt condenser.
C7—.25-μfd. Sprague condenser.
C8—250-μμfd. fixed grid condenser.
C9—500-μμfd. fixed condenser.
C10—4,000-μμfd. fixed conde ser.
C11—100-μμfd. fixed tuning condenser.
R1—4-megohm gridleak.
R2—6-megohm gridleak.
R3—2-megohm gridleak.
R4—50,000-ohm Frost variable resistor.
R5—15-ohm fixed filament resistor.
R6—2-ohm Carter rheostat.
R7—100,000-ohm Frost variable resistor. Oscillator voltage and volume control.
L1, 2, 3—1st-detector coils on Silver-Marshall type 130P coil form.
L4, 5—Oscillator coils on same type form.
L6—120 turns of 26 gauge d.c.c. wire wound in a 1½"-diameter hank.
L7—300 turns of 30 gauge s.s.c. wire on 2" outside diameter bakelite tubing.
L8—12 turns of 28 gauge d.c.c. wire wound in a 1½"-diameter hank.
RFC—Silver Marshall type 277 radio-frequency chokes. In order to avoid complicating the diagram, no shielding has been indicated. All battery leads are made with a Yaxley battery cable type No. 660, the connector plate of which can be seen at the rear center of the base-board.

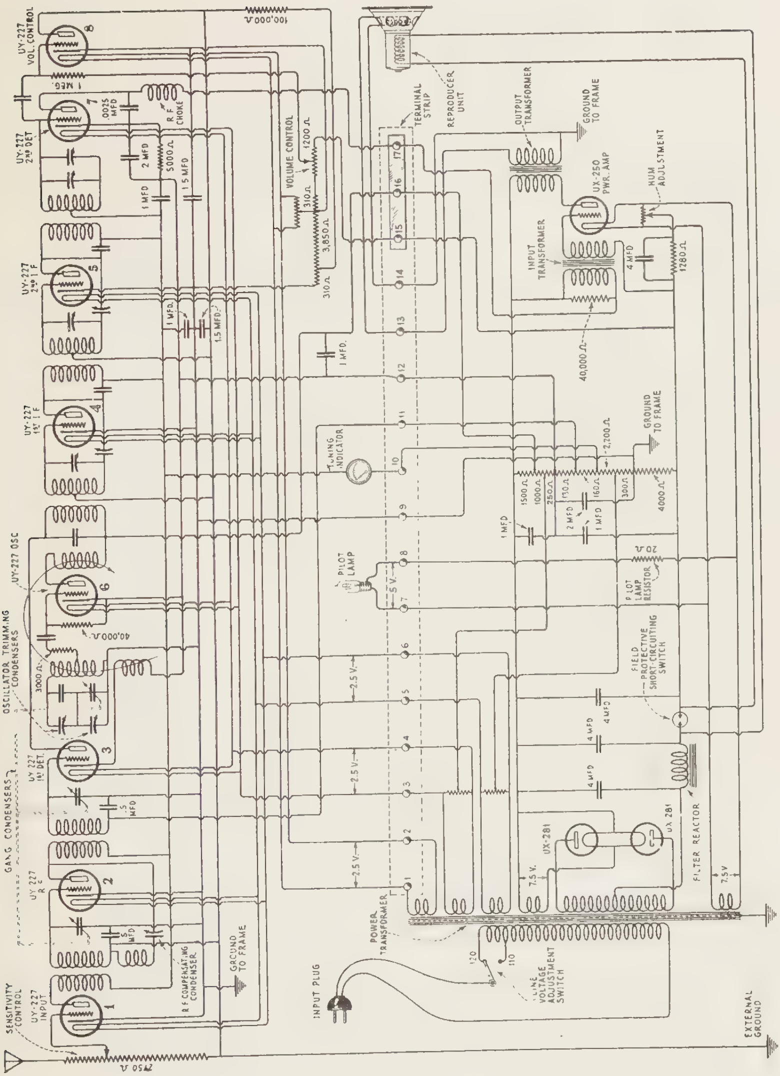


FIGURE 22. Schematic circuit diagram of Radiola 64.

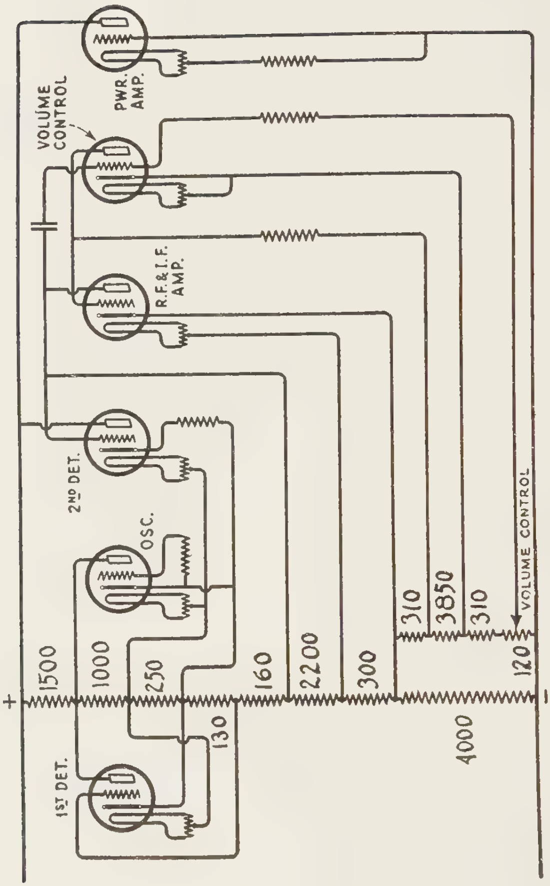


FIGURE 23. Schematic circuit diagram of voltage supply system and volume control.

CHAPTER XXVI

AUDIO AMPLIFICATION

352. Three Classes of Amplifiers. There are three general classes of audio amplifiers—resistance amplifiers, impedance amplifiers, and transformer amplifiers.

Amplifiers have been treated to some extent with the receivers. They are also used in transmitters. The quality of the receiver and transmitter, to a large extent, depends on the amplifier.

353. Resistance Amplifier. In Chapter XIII, we have seen that the coupling coefficient of a resistance is $R/(R+R_p)$ where R is the coupling resistance and R_p is the resistance of the tube. Thus the coupling coefficient is always less than unity. The amplification constant, μ, depends on the potential of the plate of the tube and in order to keep the plate potential at a reasonable value the B battery potential must be great. If the coupling coefficient is 1/2, $R=R_p$, and if the plate potential is to be 45 volts, the potential of the B battery must be 90 volts.

Theoretically the fall of potential through a resistance is independent of frequency, and a resistance amplifier should be good at radio as well as audio frequency. Capacity effects, however, come into play at radio frequency so that radio amplification is not effective with resistance coupling. The capacity across and through the resistance is so great the signal is largely lost. In practice, resistance amplification is used only for audio amplification. A resistance amplifier, if properly constructed, will pass all audio frequencies with the same intensity. To get great amplification per stage, the tube must have a large amplification constant. Large μ usually means large plate resistance so that large resistances and large B batteries potentials must be used.

Figure 1 is a diagram of a two stage resistance amplifier connected for test of amplification. The coupling resistance is r and r_1 is the grid leak resistance. The condenser C must be large compared with the capacity of the tube—about one microfarad. The resistance of r should be equal to the resistance of the tube. 100,000 ohms or more is used in some of the best audio amplifiers,

the battery being about 200 volts. The resistance, r_1, the grid leak resistance, should be comparable with the grid impedance of the tube, $1/C\omega$, where C is the capacity of the tube and ω is $2\pi n$. If the grid leak is connected to the negative filament the average potential of the grid will be zero or a little negative of zero. If the grid picks up electrons during the time it is positive, due to a positive signal excursion, the grid current flowing through the grid resistance will make the average grid potential negative with respect to the filament connection by an amount equal to Ir_1. Thus the working conditions of the tube depend upon the value of the grid leak.

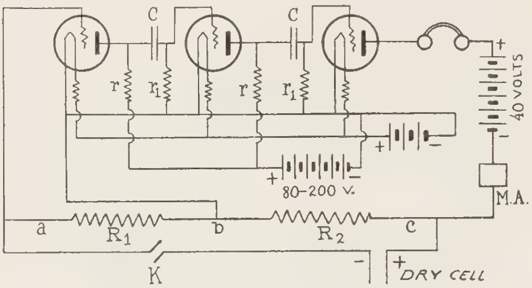


FIGURE 1.

If the mutual characteristic is obtained for the tube with the given resistance r, in series with the plate, and a D.C. milliammeter is placed in the plate circuit of the tube in the amplifier, the general conditions can be determined.

354. Choice of Resistance. It has been shown that for maximum voltage amplification the load resistance should be large. However, this involves other conditions, one being that the potential of the B battery must be large when the resistance is large. All the tubes of a resistance amplifier are used as voltage amplifiers except the last stage, which is usually a power amplifier.

From the theory of reflections it has been shown, see Chapter XXVII, that in general the condition for no reflection, or no distortion, is that the input and output impedances must be equal. For maximum undistorted output, elimination of second harmonic, in a power tube, the load resistance should be twice the resistance of the tube. For maximum power output in a circuit it can be shown that the load resistance should be equal to the resistance of the tube. There seems to be a discrepancy in the case of a power

tube between the two theories of maximum output. The general practice is to keep the load resistance or coupling resistance equal to or greater than the resistance of the tube. The load resistance should not be more than twice that of the tube.

355. Grid Leak Resistance. The impedance of the grid leak resistance should be very large compared to the grid impedance of the tube, in order that the signal will not be diminished by following the grid leak route. The grid leak and grid condenser through the action of grid current acts as a C battery, in that the condenser tends to take a negative charge. If the resistance is too high the negative bias may be too great and block the tube. Thus, there is usually a compromise in the value of the grid resistance. It is easily seen that the voltage swing of the grid of the tubes is successively larger as we go toward the output tube. The grid current in the last stages will be larger than that in the first stages. Thus the grid resistance of the first stages can be larger than that in the last stage. The adjustment must be so the tube operates on the steep straight portion of the mutual characteristic. The curve should be taken with the coupling resistance in series with the plate.

The grid swing being small in the first stage, the operation point need not be so high as in the last stage. The operating point should be high enough so the swing toward negative potentials is not on the curved portion of the characteristic.

In some amplifiers the grid bias is increased by negative C batteries placed in series with the grid resistance.

356. Condensers. Although a resistance amplifier is supposed to be free of frequency characteristics because this is true of resistances, it is not absolutely true that the amplifier is free from resonance peaks. Since the signal is communicated from tube to tube by a condenser, it perhaps might be less misleading if this type of amplifier were called a condenser amplifier.

The signal is communicated from tube to tube through the coupling condenser. The impedance of the condenser should be low; accordingly the capacity of the condenser must be large. However, there are certain difficulties with the use of large condensers which must be overcome before they are a success. One of the remedies given for the cure of "motor-boating" is a smaller coupling condenser. "Motor-boating" is a frequency effect

or noise that is peculiar to resistance amplifiers, which are supposed to be free from frequency effects.

The value of the coupling condensers given in some resistance amplifiers is .006 m.f. Condensers as large as 1. m.f. are used in others. With large condensers, it is often necessary to insert radio frequency choke coils in the circuits to stabilize the amplifier. An amplifier, to respond to low notes, must have a rather large condenser.

357. Motor Boating. "Motor boating" is a thumping noise which occurs in amplifiers. This may be caused by a common B battery. If the battery has resistance the potential at the terminals depends on the current output of the battery. An increasing current in the plate of one tube causes a decreased potential on the plate of another tube. This interaction may build up into periodic variation of current. Large by-pass condensers placed around the battery tends to steady the potential of the battery. Smaller grid leak resistances usually help.

A second cause of this noise may be an oscillating tube. With large condensers and small inductance of the order of a single turn of wire—the inductance of the resistance and tube circuits—it often happens that there are high frequency currents generated in the amplifier. As a usual thing there is a change of the D.C. current when the tube starts oscillating. The swing of the grid of the tube increases the grid current and this causes the grid to take a negative potential. This negative potential may become so great that the plate current becomes zero and stops the oscillation. The charge on the grid condenser leaks off until the potential of the grid has increased enough for the oscillation to start again. This diminution and increase of the average current in the plate circuit causes an audio frequency howl in the phone or loud speaker. If the pitch is 100 vibrations per second, the oscillations start up and stop 100 times per second. The frequency of these starts and stops or thumps may be so low that the frequency can be counted.

A remedy for the above is to diminish the resistance of the grid leak. This makes it so that the tube can oscillate all the time and the average plate current is constant at a reasonable value. A better method is to insert radio frequency chokes in the amplifier and stop the radio frequency oscillations.

358. Impedance Amplification. Impedance amplification is much like resistance amplification. Instead of a load resistance or coupling resistance, an impedance coil or retard coil is used. This makes a low resistance path for the D.C. and a high impedance for the A.C. Figure 2 is a diagram of two tubes connected by impedance coupling. The impedance must be rather high, and there may be resonance peaks or frequencies. If the retard coil has a large number of turns, the self-capacity of the coil may pass the higher frequencies.

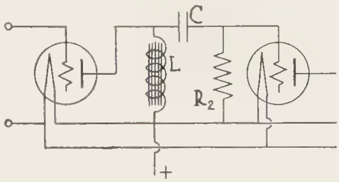


FIGURE 2.

With a good retard coil, good amplification is obtained without excessive B potential. It will be noted that impedance amplification is used in many commercial forms of amplifiers.

359. Audio Transformer Amplifiers. The audio transformer coupled amplifier is perhaps the easiest to construct and operate. With more than two stages, there is often howling, due to circuit feed back at audio frequencies. This can often be remedied by reversing a connection on a transformer. Resistances of the order of grid leak resistances placed across the terminals of the secondary coils usually load the secondaries so the oscillations cease. This load may often improve the quality by "balancing" the loads on the tubes.

360. Quality Audio Transformers. A perfect transformer is one in which there is no resistance, no hysteresis and eddy current loss and one in which the flux through the core can build up to the point that the back E.M.F. is equal to the impressed E.M.F., without approaching the "knee" of the magnetization curve. Since the back E.M.F. is proportional to the number of turns times the flux through the core or is proportional to the inductance L, it is seen that for low frequency, since $E = LI\omega$, the number of turns of wire must be great or the cross section of the core must be great. If the number of turns are increased, the number of turns on the secondary must be greater. If the number of turns on the secondary becomes too great, the capacity of the windings becomes great and we get resonance at some of the high frequencies. This, of course, produces distortion.

The other course is to increase the cross section of the iron core. During the last two years there has been a great improvement in audio transformers. To the casual observer the increased size is the most noticeable. The quality of the iron core and the thinness of the laminations have effects. A modern transformer amplifier gives response curves which rival the best resistance coupled amplifiers. The usual voltage ratio of a transformer is three or four. Higher ratios are used, but they may cause distortion.

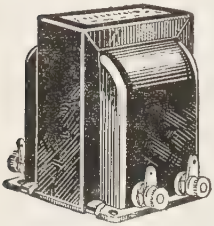


FIGURE 3.

Figure 3 is a modern quality transformer.

Figure 4 is an audio amplifier using rectifying tubes and battery eliminators To use this amplifier, power is supplied from a 60 cycle lamp socket.

361. Power Amplifiers. In the article on tubes it was stated that we do not give the ratio of the power in the grid of a tube to the power delivered in the plate circuit, since that has no definite meaning. We defined A_{pv} as the power delivered in the plate circuit per volt squared in the grid circuit. In the same manner the output of a power amplifier should be expressed in watts delivered by the last tube per volt on the grid of the first tube. As stated before, in an amplifier all tubes except the last are voltage amplifiers.

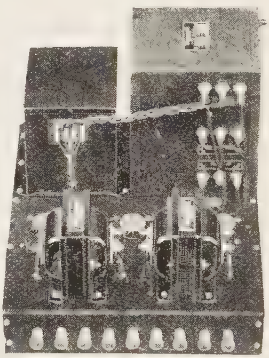


FIGURE 4

362. Calculation of Power. In power amplifiers and in tubes, the D.C. currents, filament and plate, are not taken into the calculation. The filament temperature and the B battery bring about certain conditions under which the tube operates and the energy necessary to keep the tube in this condition is not taken into account.

In Figure 4, Chapter XII, we have a mutual characteristic of a tube. The characteristics are drawn for zero resistance and for 25000 ohms resistance in the plate circuit.

Assume we have a B battery of 90 volts in the plate circuit and that we must keep the mean grid potential zero. Then a D.C. ammeter will show about 1.8 milliamperes in the plate circuit. If we apply positive potential, five volts to the grid, the plate current is 2.8 mil. amp. If the potential is negative five volts, the current is about .8 mil. amp. The total change of grid potential is 10 volts. But this is an alternating potential. The virtual value is $5/\sqrt{2}$ volts. In like manner the total change of current is 2 mil. amp. and the virtual value of this is the maximum swing on either side divided by the square root of two, or $1/\sqrt{2}$ mil. amperes. This is grid potential, and the plate potential is μ times this, so the power is

$$(\mu 5/\sqrt{2})(1/\sqrt{2}) = \mu 5/2 \text{ milli watts.}$$

If we double the grid potential and work between plus and minus 10 volts we have a total change of current a little less than 4 mil.-amps. Then our A.C. potential is $10/\sqrt{2}$ and the current is $2/\sqrt{2}$. The power is $\mu 20/2 = 10$ milliwatts. This brings out the fact that the power is proportional to the volts squared.

The plate characteristics lend themselves to computation of power better than the mutual characteristics.

In the last calculation we said that the current was a little less than 4 mil. amps. It is really only 3.5 mil. amps. This is due to the curvature of the characteristic curve near the bottom. Another effect which does not show up on the curve is that there will be distortion due to the fact that to the right of grid zero line we have grid current. Since these curves were taken with direct current, distortion apparently does not show up. But with alternating current there will be distortion due to the grid current. To prevent distortion we are limited in the voltages we can use. We must use the curve to the left of zero and not go too far to the left. Perhaps we can safely say we can work between zero and negative eight. To do this we must have a negative C battery of 4 volts. Our current will then be from .5 mil. amp. to 3.8 mil. amps. The power then is $(\mu/8)(4 \times 3.3)$ mil. watts. This is the undistorted output of the tube at 90 volts on the plate, assuming our characteristic is a straight line.

363. Use of Plate Curve. The plate characteristic curves lend themselves to the calculation of power. Figure 5 is the plate

characteristic of a 371 tube. The straight line AC shows the variation of potential when the tube is connected to a load resistance of

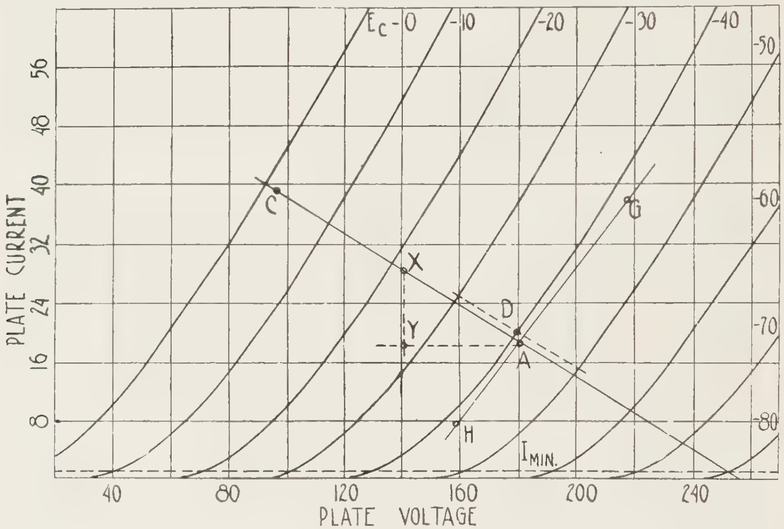


FIGURE 5.

4000 ohms. The negative reciprocal of the slope of this line is the resistance. On this line at 180 volts we have a current of 20 mil. amps.

$$.020 \times 4000 = 80 \text{ volts.} \qquad 180 + 80 = 260 \text{ volts.}$$

This is the potential of the B battery necessary to put a potential of 180 volts on the plate when the current is 20 milliamperes.

The maximum potential swing of the plate can be about 75 volts on either side of 180 volts, or from 105 volts to 255 volts. The current swing is from 2 to 38 milliamperes. If this is alternating current, the current is $\frac{1}{2}(36)/\sqrt{2} = 18/\sqrt{2}$; the A.C. voltage is $75/\sqrt{2}$; the power is $1350/2 = 675$ milliwatts. The grid potential is about -40 volts. With 260 volts in the B battery we must use a -40 volt C battery, the average potential on the plate being 180 volts.

364. Limits of Power. It will at once suggest itself to one that all that is necessary to increase the output of a tube is to increase the B battery potential and the negative grid bias. There are limits to this. The tube is insulated in the base and in the mash

for a certain maximum voltage. If higher voltages are applied this insulation is liable to break down. And again, in an amplifier there will be times when the tube will be idle. The plate must be able to dissipate the energy of the B battery when the tube is not in use. The tube can be run at a dull red heat but not at white heat. This last, the safe dissipation, limits the power. It will be apparent the power can be increased if we can allow some distortion, provided the tube is not damaged.

365. Distortion. Distortion in amplifiers can be introduced, as has been stated, if the tube is overloaded. By overload it is meant that the grid swing on the characteristic curve is to the point on the right where grid current flows, and t the minimum value, the point on the left, where the curves are not straight at the foot of the characteristic. Distortion can also be introduced in the coupling coil. If the signals are great enough to swing the current in the transformer so it works near to or above the knee of the magnetization curve of the core of the transformer, distortion will be introduced.

Figure 6, is a magnetization curve for a sample of iron—a *BH* curve as it is sometimes called. It shows the relation of the current in the primary coil to the E.M.F. in the secondary coil. As long as we operate below the bend of the curve, the current and E.M.F. produced are proportional. If the current becomes too great the E.M.F. is not proportional to the signal and the signals are distorted. Hysteresis losses also increase with the strength of the current and introduce distortion.

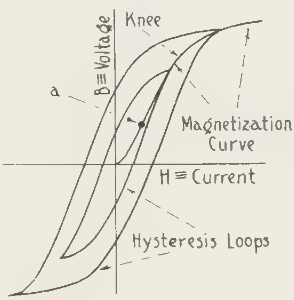


Figure 6.

A transformer in the last stages is liable to be overloaded. It should be determined beforehand that the transformer is large enough to care for the loudest signal.

366. Effect of Plate Current. In audio amplifiers there is a direct current through the primary coil. This current places the point of operation at some point such as at *a* in Figure 6, instead of at zero. This limits the capacity of the transformer and is liable to introduce distortion.

367. Push Pull Amplification. In push pull amplifiers we have special transformers as illustrated in Figure 7. The input transformer has a secondary coil with a connection made at the center of the coil. This is called a mid-tap. The output transformer has a mid-tap on the primary coil. Two tubes are connected in parallel. The filaments with the proper amount of C battery bias are connected to the mid-tap of the secondary of the input transformer. The grids are connected to the two terminals of that coil. The plates are connected to the terminals of the primary of the output transformer and the positive terminal of the B battery is connected to the transformer's mid-tap.

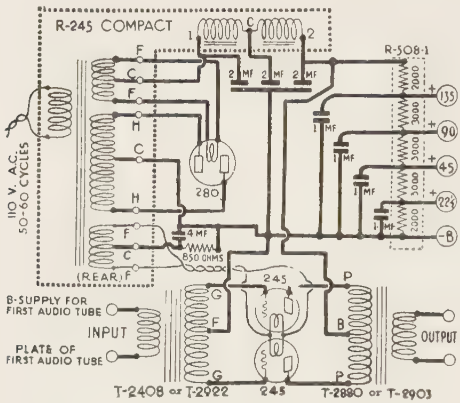


FIGURE 7. Thordardson R-245 push pull amplifier with power supply.

When a signal is introduced into the input transformer the grid of the first tube is positive, while the grid of the second is negative. The plate current of one tube is increasing as the plate current of the second is diminishing. The increasing current and the diminishing current induce a current in the secondary of the output transformer in the same direction. The tubes are in parallel and the power capacity is twice that of one tube.

Distortion is diminished in two ways. If the signal is such as to throw the operating point down on the curved part of the characteristic in one tube the other tube is operating on the upper or straight part of the curve. This averages the effects in the input transformer. In the output transformer the plate currents are flowing in the opposite directions and the D.C. components neutralize the magnetization effects in the transformer. The signals are symmetrical with respect to the zero point on the magnetization curve of the transformer, independent of the amount of D.C. plate current. In this manner the full capacity of

the last, the output, transformer can be used without distortion, and as a usual thing it is the last transformer which is overloaded.

368. Conditions for Maximum Output, Low Distortion in Power Tubes. In Figure 8 we have a power tube connected to a load resistance in the plate circuit. The problem is to find the value of the resistance, R, which will give maximum output when there is no distortion. Distortion is introduced when the grid is positive enough to have grid current and when the point of operation on the curve is on the lower bend.

FIGURE 8.

Figure 9 shows the plate characteristic curves for the tube. The grid current is supposed to flow when the potential of the grid is higher than zero. The horizontal line marked $I_{\text{min.}}$ gives the lower limit of the current in order to avoid distortion represented by the lower curve of the characteristic.

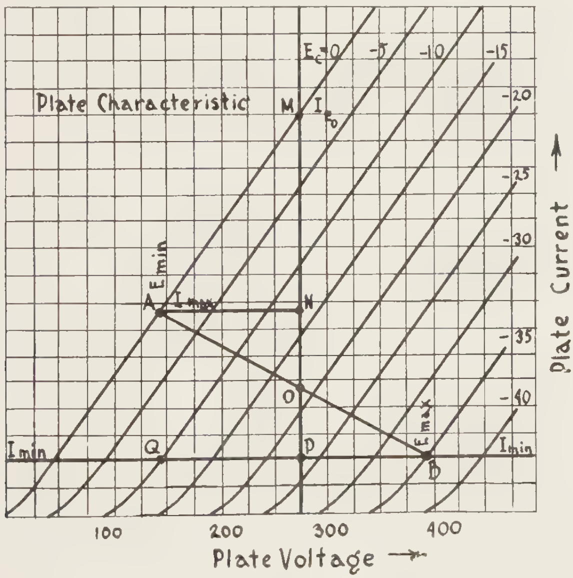


FIGURE 9.

The line AOB is drawn such that the tangent of the angle OBP is equal to the reciprocal of the resistance, R. This will be seen

if we remember that the potential of the plate, $Pd=E-IR$, where E is the E.M.F. of the B battery. Then $R=(E-Pd)/I$. But the tangent OBP is equal to current divided by electromotive force. It is well to remember that the slope of the plate characteristic is equal to the reciprocal of the plate resistance, R_p, Chapter XI.

Suppose the B and C batteries are adjusted for steady conditions. The point of operation is at O, and an alternating potential is placed on the grid which will swing the current and potentials between the limits A and B. The current change is $(I_{\text{max.}}-I_{\text{min.}})$ and the potential change is $(E_{\text{max.}}-E_{\text{min.}})$. The virtual current will be the swing of current to either side divided by the square root of two.

$$I_{\text{virt.}}=(I_{\text{max.}}-I_{\text{min.}})/2\sqrt{2} \quad \text{and} \quad E_{\text{virt.}}=(E_{\text{max.}}-E_{\text{min.}})/2\sqrt{2}.$$

$$\text{Power, } P=EI=\tfrac{1}{8}(E_{\text{max.}}-E_{\text{min.}})(I_{\text{max.}}-I_{\text{min.}})=(BQ)(AQ)/8.$$

The resistance, $R=BQ/AQ$. The tube resistance, $R_p=AN/MN=1/2\ (BQ/MN)$, so that $BQ=2R_p(MN)$. And power, $P=R_p(MN)(AQ)/4=R_p(MN)(NP)/4$. But $MN+NP=\text{const.}$ and since the power is equal to their product the power will be a maximum when $MN=NP$.

Since

$$R=BQ/AQ=BQ/NP=BQ/MN \quad \text{and} \quad R_p=\tfrac{1}{2}(BQ)(MN)$$

$$R=2R_p.$$

The load resistance equals twice the tube resistance for maximum undistorted output. This, however, is not the condition for maximum power amplification. Maximum power amplification is met with when the load resistance is equal to the resistance of the tube. This is illustrated in Figure 10.

It must be remembered that maximum undistorted power here is calculated on the assumption that the grid swing will be a certain amount. In application this will be for the most intense sounds. The output can be increased by allowing a certain amount of distortion on the loud notes. The limits then will be a certain amount beyond the grid current limit and to some extent on the lower curve of the characteristic.

369. Percent of Distortion. The percent of distortion produced by this adjustment can be calculated from the formula which will be apparent.

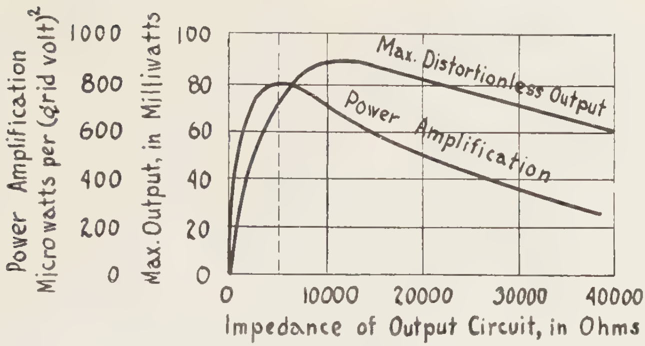


FIGURE 10.

$$\text{Percent Distortion} = \frac{[(I_{\max.} + I_{\min.})/2] - I_0}{(I_{\max.} - I_{\min.})}.$$

One can see by referring to Figure 11 that if the curves were straight lines the distortion as calculated by this formula would be zero.

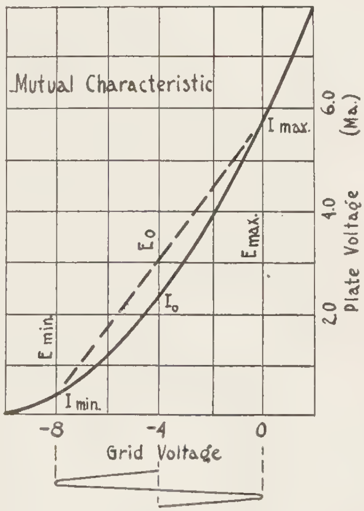


FIGURE 11.

The above theory assumes a pure resistance load. It has been found that an inductive load does not introduce much more distortion under normal conditions. (Proc. Phys. Lon. 36, 221.)

Care must be exercised in adjusting the tube not to overload it. There will be times when the tube is idle and the plate must be able to dissipate the energy.

370. Choice of Tubes. In amplifiers all but the last tube are voltage amplifiers. The general rule is to use a small amplifier tube as long as the tube is not overloaded.

The following table gives data for the common tubes used as amplifiers:

AMPLIFYING TUBE DATA

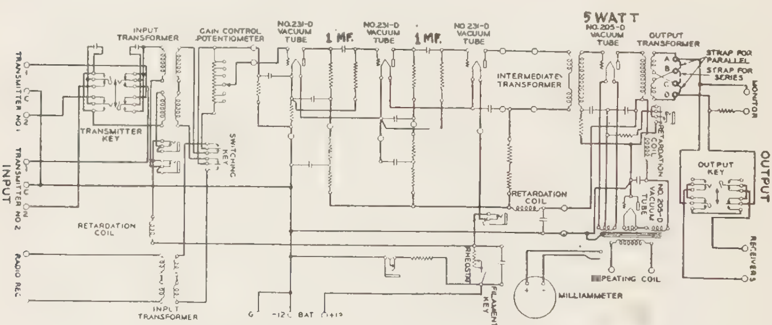
	Plate Voltage	Grid Bias	D.-C. Plate Current (Milliamperes)	Amplification Factor	Plate Resistance (Ohms)	Mutual Conductance (Micromhos)	Load Resistance	$\frac{\mu}{R_p+r_p}$ Output Current per Volt (Microamperes)	$\frac{\mu R_p}{R_p+r_p}$ Output Voltage per Volt Input	$\frac{\mu^2 R_p}{(R_p+r_p)_2}$ Output Power per Volt Squared Input Milliwatts)	A-C Grid Voltage (R.M.S.) for P_{max}	Maximum Uudistorted Output (Milliwatts)
Tube	E_b	E_c	I_b	μ	r_p	g_m	R_p	A_c	A_v	A_p	E_g	P_{ma}
UX-199	90	− 4.5	2.5	6.5	15250	425	15250	212	3.25	.690	3.18	7
	90	− 7.5	1.3	6.45	19250	335	32000	126	4.00	.505	5.30	14
UX-201-A	90	− 4.5	2.0	8.5	12000	708	15000	315	4.70	1.480	3.18	14
	90	− 6.0	1.2	8.4	15400	550	30000	185	5.55	1.025	4.24	17
	135	− 9.0	2.55	8.4	11000	764	22000	255	5.60	1.430	6.36	55
UX-240	180	− 4.5	.2	30.	150000	200	300000	67.5	20	2.	1.5	5
UX-120	135	−22.5	7.0	3.3	6600	500	6660	250	1.65	.412	15.90	105
	135	−26.7	5.5	3.2	7500	427	15000	142	2.13	.302	18.90	110
UX-226-A.C.	180	−13.	7.5	8.6	7000	1170	14000	410	5.5	1.4	7	160

AMPLIFYING TUBE DATA (*Continued*).

UX-171	90	−16.5	10.0	3.0	2350	1275	4000	472	1.89	.893	11.58	105
UX-171-A	135	−27.0	16.0	2.9	2100	1380	4000	475	1.90	.902	19.10	320
	180	−40.5	20.0	2.9	2000	1450	4000	483	1.93	.934	28.60	710
112 or 112A	135	− 9	7	8	5000	1600	10000	266	5.3	7.5	4.	120
UX-210	135	− 9.0	5.0	7.5	8000	940	15000	326	4.89	1.59	6.36	64
	250	−18.0	11.5	7.5	5600	1340	11000	451	4.97	2.25	12.72	340
	400	−35.0	16.0	7.5	5400	1390	11000	457	5.03	2.30	24.80	1340
UV-203-A	1000	−22.5	26.0	25.0	8800	2840	17600	947	16.70	15.80	15.90	3920
UV-211	1000	−48.5	75.0	12.0	3400	3530	6800	1177	8.00	9.41	34.30	11000
250	250	−45.	28.	3.8	2100		4200				25.	900
	300	−65.	45.	3.8	1900	2100	3900				38.	2350
	450	−84.	55.	3.7	1800		3600				60.	4600
245	180	−33.	26.	3.5	1900	1850	3800				30.	1600
	250	−50.	32.	3.5								
222	180	Screen grid		300	.85 mg	350						
224	180	A.C. Screen grid		350	.4 mg	1050						

It may be well to call attention to the fact that the table gives E_g for maximum undistorted power. The A.C. voltage on the grid should never be greater than this value. The grid bias should be that in column, E_c, if the voltage on the grid is maximum. If the A.C. grid voltage is much less, the value of E_c can be a greater negative value than this. The point of operation must be on the straight line of the characteristic, but the B battery current can be diminished by using more negative bias. With a large tube the plate may become too hot when the tube is idle. The safe dissipation is given in the table in Chapter XIV. This table can be consulted on this point. In the last stage a tube is wanted which will give the most power per volts squared, provided the tube is not overloaded.

If the intermediate stages do not increase the voltage to a point such that the last tube, power tube, is overloaded, it will, as a general thing, do no good to use a larger tube in the last stage. If the voltage on the grid of the power tube is less than 6.36, it will do no good to substitute a 171 tube for the 201A. It will do very little good to use a 210 tube. A one horsepower engine can carry a one horsepower load as well as a ten horsepower and do it much more economically.



Schematic of the No. 32-A Amplifier

FIGURE 12.

The tube must in all cases be coupled to a load—loud speaker—which will match the impedance of the tube. If the load is not matched a transformer of suitable design must be used to couple the load to the tube.

371. Examples of Modern Amplifiers. Figure 12 is a diagram of a Western Electric Company amplifier used for amplification in a small public address system. The maximum output is a five watt tube. Three small tubes are resistance coupled together to amplify the voltage. These tubes are transformer coupled to the last tube.

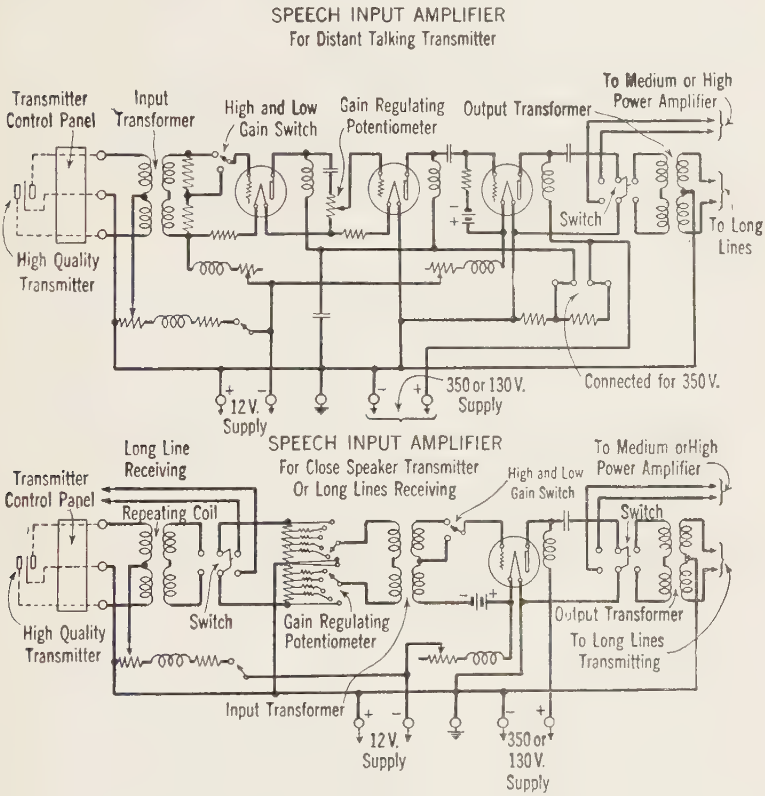


FIGURE 13.

The condensers used as coupling are large condensers. The power is taken from the lighting circuit. A five watt tube, 205D, with the grid and plate connected together, is used as a two electrode tube rectifier. This is a combination of resistance and transformer coupled amplifier.

Figure 13 is a diagram of two amplifiers. The top is the amplifier used at a distant studio. The speech is amplified and placed on the long distance telephone lines. In the case of the second amplifier, at the bottom of the figure, the speech is picked up from the long distance lines at the transmitting station, is amplified and placed on the power amplifier of the station. Or the bottom amplifier may be used as a repeating amplifier for trans-continental transmission.

Figure 20 Chapter XXIV, is a diagram of a Western Electric 5 K.W. broadcasting station, showing an audio speech input amplifier. This is an impedance coupled amplifier. In the oscillating circuit amplifier we have a combination of impedance and transformer coupled circuits.

Figure 19, Chapter XXIV, is a diagram of a 1 K.W. transmitter. We have resistance coupling in the speech input amplifier. It is noticeable that where audio transformers are used the secondary coil is loaded with a resistance. In this manner the balance of loads may be obtained. The power taken by the grid of a tube is rather uncertain. The resistance makes a real load and the grid potential is that across the load.

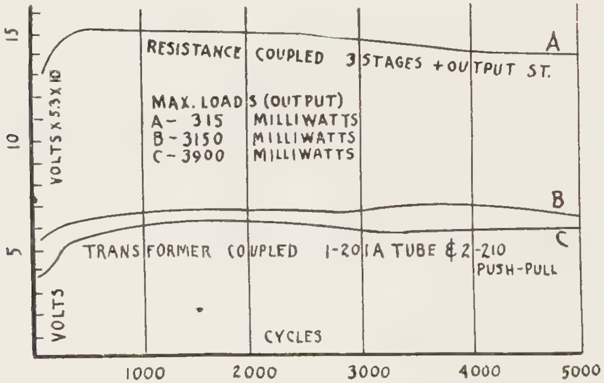


FIGURE 14.

Figure 7 is a diagram of a push pull Thordarsen amplifier using 245 tubes. This amplifier is constructed to connect to the lamp socket. Since the plate potential for the 245 tube is relatively low, a single 280 rectifying tube furnishes the plate potential for the amplifier and the set.

Figure 14 shows a response curve in which the output potential at the load is measured against frequency. The voltages shown depend upon whether the load was low or high impedance. The resistance load was a high impedance. This makes the voltage high. The test is in the "flatness" of the curves.

In curve *C*, the amplifier was slightly overloaded.

CHAPTER XXVII

BALANCED CIRCUITS

372. Reflections. A balanced circuit is one which is so arranged or connected that there will be no distortion of the signals. This condition will be seen to be necessary in circuits connected with Radio Broadcast apparatus. In apparatus used in testing transmitters and other apparatus it is necessary to see that the test instruments do not change the conditions so that the results are worthless.

The fundamental condition is that there be no "reflections." In the audio part of radio receiving apparatus we are dealing with alternating current of many frequencies. If there are reflections the reflected energy may produce interference effects with the energy as represented by the incident current or waves. This energy of a particular frequency combining with waves of a second frequency may produce waves of another frequency.

This third frequency not being in the transmitted wave may produce distortion in the received current producing poor quality in the tones from the loud speaker.

In electrical transmission of power the frequency of the current is one frequency alone, any reflections produced will have the same frequency and any number of waves combining in any manner always produce a resultant wave of the same frequency. So the balanced circuit is not thought of in ordinary power transmission. The criterion in power circuits is maximum efficiency. The efficiency of power apparatus usually is from 80% to 95% or over. In broadcast audio transmission, efficiency is forgotten in the attempt to get quality.

373. Rope Analogy. If one has a long rope stretched and tied at both ends it is possible with little effort to produce what are known as standing waves. If the stretched rope is struck near one end a sharp blow with the hand or a stick a wave will be seen to run as a trough to the far end and then come back as a crest and then be reflected from the near end again as a trough. If the rope is struck at regular intervals, intervals which are commensurate

with the motions of the wave on the rope it will be seen that standing waves are formed. Crests always meet troughs at certain points and produce nodes, and crests always meet crests at certain points and troughs meet troughs at the same points and produce points of great disturbance. Thus the disturbance on the rope at any instant is made up, largely, of the disturbances which were started a considerable time before.

If the rope were infinitely long the disturbance or trough would go out to infinity and never come back and we would have no standing waves or reflections. If the end of the rope were so arranged that it could absorb the motion of our trough when it hits the end there would be no reflections and it would be impossible to produce standing waves by reflection.

In our electrical circuit if the output impedance can be arranged to absorb all the energy as it comes then there will be no reflections and no distortion. Under this condition the load is a balanced load.

374. Condition for Balance. The theoretical consideration is too far advanced to give here but it can be shown that this condition is met when the output impedance is equal to the input impedance. Pierce's Electrical Oscillations, equation (37), p. 293.

This condition is also the condition for maximum output of an electrical circuit. In Chapter I we have shown that the maximum output of a battery is obtained when the external resistance is equal to the internal resistance of the battery. The two conditions happen to be the same. We make the output impedance equal to the input impedance in order to have no reflections and not because we wish a maximum output. We are willing to sacrifice efficiency, maximum output, and most everything else in order to get quality transmission. Fortunately we do not need to sacrifice maximum output.

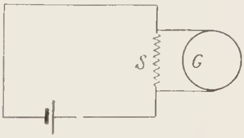


FIGURE 1

375. Attenuators. An attenuator is a shunt so arranged that the circuit is balanced. Perhaps we might say an attenuator is a "quality shunt." If we have a shunt as in Figure 1 connected to a galvanometer it can be shown that $I_g = IS/(S+G)$ where I_g and I are the currents in the galvanometer and the total current through the battery respectively, and S and G are the shunt and

galvanometer resistance. If we assume the circuit is balanced before the galvanometer is shunted, i.e. the galvanometer and battery have the same resistance, the circuit is not balanced after the shunt is placed across. If I_g is 1/10 of I, then the resistance of the shunt is 1/9 of the galvanometer resistance and the resistance in series with the battery is less than 1/9 the galvanometer resistance.

If we wish to keep the circuit balanced we must put an extra resistance in series with the battery and also a resistance in series with the galvanometer as well as the shunt. In that case we have a circuit like that of Figure 2.

We have a shunt or attenuator made up of two resistances, X, and the shunt resistance, Y, connected to a source and sink. Since the impedances are supposed to match without the attenuator the two impedances, or resistances of the source and sink must be equal. Assume these impedances are Z ohms. With the attenuator in the circuit the impedance of the attenuator, looking from the source to the attenuator, must be equal to Z ohms. Likewise the attenuator looking backward from the sink to the attenuator must have Z ohms. The resistance of the shunt combination looking into either end of the attenuator is $X+[Y(X+Z)/(Y+X+Z)]=Z$. From this we have $Y=(Z^2-X^2)/2X$. In terms of the equation of a shunted galvanometer, we have

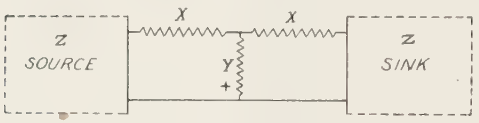


FIGURE 2.

$$I=I_0Y/(Y+X+Z) \text{ or } Y+X+Z=kY \text{ where } k=I_0/I$$

From this we get $Y=(X+Z)/(k-1)$. Combining these two values of Y we get,

$$X=Z(k-1)/(k+1). \tag{1}$$

Substituting this value of X into the value of Y we get

$$Y=2Zk/(k^2-1). \tag{2}$$

It is usual to make the form of the attenuator into the form of Figure 3 in which the X of Figure 2 is divided into equal parts then

$$X = (Z/2)(k-1)/(k+1). \tag{3}$$

This renders it so that the attenuator can be grounded at its middle point by grounding the middle point of Y.

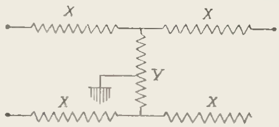


FIGURE 3.

Attenuators are made so that the attenuation or shunting can be changed from one value to another simply by moving switches. Figure 4 gives the diagram of such an attenuator. Figure 5 shows an attenuator made by the General Radio Company. These attenuators are made to match a certain impedance, Z, 6000 ohms, 600 ohms etc., and should not be used except in circuits in which the impedance matches that of the attenuator.

The attenuation can be given in terms of k or rather in terms of $1/k$, the reciprocal of the ratio of currents. It is usual to give the attenuation in terms of decibels, db, where $k = 10^{n/20}$, or N, the number of decibels, is twenty times the logarithm to the base ten of k. $N = 20 \log_{10} I_0/I$. The decibel is the same thing as the transmission unit.

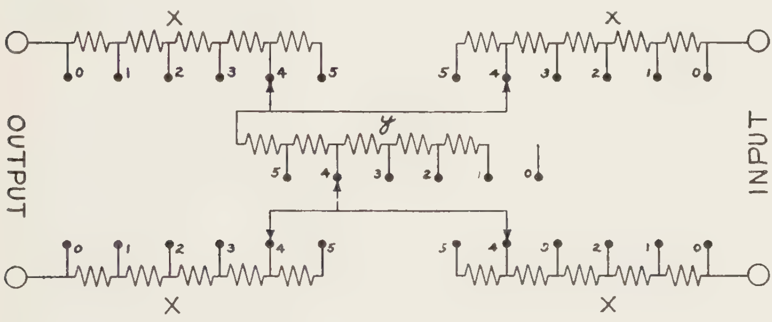


FIGURE 4.

376. Decibel. The decibel or transmission unit as it was formerly used is a unit which has developed in telephone transmission work and has been applied to circuits and apparatus

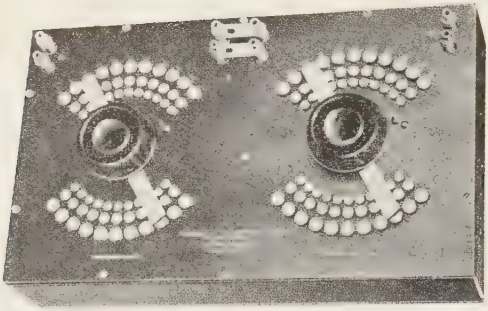


FIGURE 5.

which produce sound. It is a natural unit based on the human ear. It has been found that the average human ear can distinguish between the intensity of two sounds if they differ in intensity by one decibel. It is found that the ear does not distinguish absolute intensities very well but when it comes to distinguishing relative intensity of two sounds the agreement is much more close. The number of decibels between two sounds is ten times the $\log_{10}$ of the ratio of the power or energy represented by the sound. Thus $N = 10 \log_{10} P_1/P_2$. Since power is proportional to the square of the current, $N = 10 \log_{10} I^2_1/I_2^2 = 20 \log_{10} I_1/I_2$. The following table gives the relative values of decibels, N, and k. Where k is the ratio of currents.

N	k	N	k
1	1.122	8	2.51
2	1.259	9	2.82
3	1.413	10	3.16
4	1.585	20	10.
5	1.778	40	100.
6	1.995	60	1000.
7	2.24	80	10000.

Divide the columns marked N by two if k is the ratio of power.

377. Decibels Up. Decibels Down. In an attenuator the attenuation is downward. The output is less than the input. Then the output is so many decibels down. In an amplifier the output is greater than the input and the attenuation is so many decibels up. In a telephone line the attenuation is down. At the repeating station where amplifiers are used the attenuation is up. The amplification makes up for the attenuation in the line proper. The level is kept above line noises.

In response curves such as that of a loud speaker some value is taken as a "zero" value. If at some points the intensity is greater than this value, it is so many decibels up or positive. If the intensity is less than this zero value, the curve is so many decibels down or negative.

378. Calculation of Decibels. In taking a set of data one can take the ratio of the power or the ratio of the current and calculate the number of decibels in each case. It is much easier when one has data like that in a response curve to arrange the readings in a column with two or three blank columns beside the data. In the first column place the values of the logarithm of the data, using a table to the base ten or a slide rule. Multiply these values by ten or by twenty according as the original values are given in power or current. Select some average value as the zero value and subtract this value from the other values. Remember $\log (x/y) = \log x - \log y$.

After the "zero" value has been subtracted from the larger values we have positive values, decibels up. After this has been subtracted from the smaller values, or rather, after the smaller values have been subtracted from the "zero" value we have decibels down.

379. Filters. A filter is a combination of coils and condensers to filter out or stop certain frequencies. It is beyond this book to go into the theory of filters and derive the equations. A general statement of the final equations will be given. A perfect filter is one which will stop the undesirable frequencies and pass the others without attenuation. Theoretically this can be done if coils and condensers without resistance can be used. With actual coils and condensers this can be approached to a degree. The cutoff frequency is that frequency at which the attenuation starts. Theoretically all frequencies on one side of this cutoff frequency are stopped and all on the other side are passed without attenuation. In actual filters this cutoff is not abrupt but more or less gradual. To calculate a filter we must know two things, the cutoff frequency and the impedance of the source and sink. It is assumed that the circuits have been matched before the filter is placed in the circuit and that the impedance of the filter matches these impedances.

We shall content ourselves with two simple filters, a low pass filter and a high pass filter. Each of these are shown in two forms,

T and π section filters. The formulas given apply to coils of zero resistance. In "sound" circuits it is usual to use honeycomb coils and apply the same equations.

A filter may be of one or more sections. As a usual thing not more than three sections are used. The two equations used are,

$$\omega_0 = 2/\sqrt{LC} \quad \text{and} \quad R = \sqrt{L/C}$$

where $\omega_0 = 2\pi n_0$, n_0 being the cut off frequency, and $R = Z$ the impedance of the source and sink. From the above we have

$$L = 2R/\omega_0 = .3183R/n_0 \text{ Henries.}$$

and

$$C = 2/\omega_0 R = .3183/(n_0 R) \text{ Farads.}$$

These equations apply to Figure 6.

Figure 6 shows a low pass T type, filter, one and three sections, also one and three sections of a π type filter.

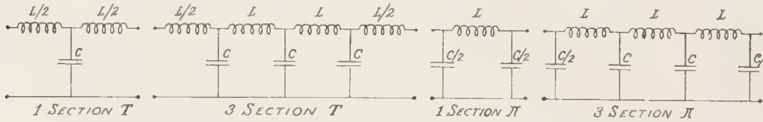


FIGURE 6.

Figure 7 shows a high pass filter, T type, one and three sections, and one and three sections of a π type, high pass filter.

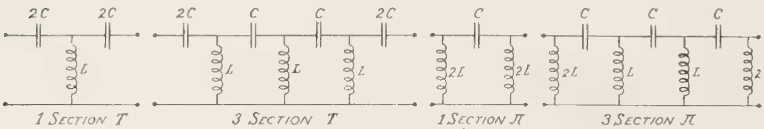


FIGURE 7.

The equations for a high pass filter are

$$\omega_0 = 1/(2\sqrt{L/C}) \quad \text{and} \quad R = \sqrt{L/C}$$

from which we get

$$L = R/2\omega_0 = .1592R/n_0 \text{ Henries.}$$

and

$$C = 1/(2\omega_0 R) = .1592/(n_0 R) \text{ Farads.}$$

For theory of filters consult Pierce's "Electrical Oscillations" Chapter 16; Johnson's "Transmission Circuits," Chapters 16 and 17. B battery eliminators have filters whose cutoff frequency is below 60 cycles.

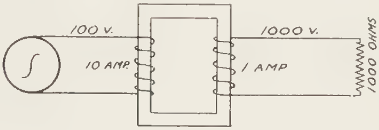


FIGURE 8.

380. Matching Impedances with a Transformer. If the impedance of the output and the impedance of the input circuits are not equal, the circuits can be coupled with a transformer of proper ratio to match the impedances.

Let us assume we have a transformer as in Figure 8 which is connected to a 100 volt generator. If the secondary coil has ten times the number of turns as are on the primary, there will be an E.M.F. of 1000 volts in the secondary. This will deliver one ampere to a resistance of 1000 ohms. The current in the primary will be 10 amperes. The generator whose E.M.F. is 100 volts could deliver 10 amperes to a resistance of 10 ohms. Thus a thousand ohms in the secondary circuit looks like ten ohms in the primary circuit. Then $R_1 = R_2(E_1/E_2)^2$ The voltage ratio is the same as the ratio of the numbers of turns of wire in the coils. Then $Z_1/Z_2 = (n_1/n_2)^2$.

FIGURE 9.

Thus if the impedances are known a transformer can be built with the proper ratio of turns so the impedances will match when the input is coupled to the output, i.e.: tube to a loud speaker.

Figure 9 is a coupling transformer made by the Samson Electric Co. If the transformer has appreciable resistance or losses, these losses must be taken into account but the above gives a good approximation to the correct result.

CHAPTER XXVIII

LOUD SPEAKERS

381. Types of Speakers. The earliest loud speakers were simply telephone head sets with horns. From this beginning there has developed what are known as electromagnetic speakers. The floating coil speaker or the electro-dynamic speaker has come into general use during the past two years. However the Magnavox loud

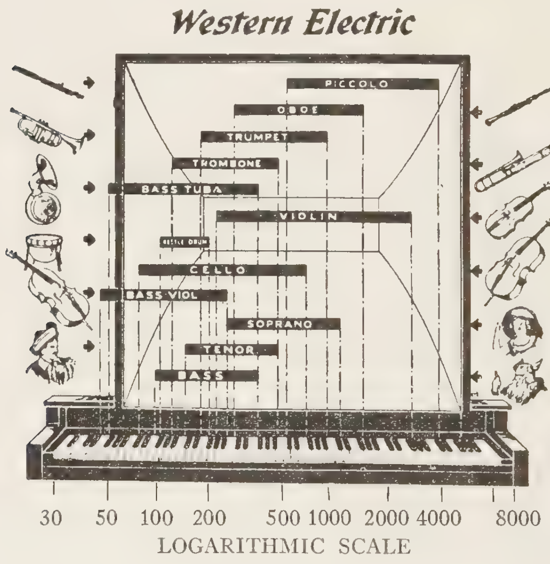


FIGURE 1.

speaker, which is a dynamic speaker, was in use before the days of broadcasting.

In recent months two new types of speakers have appeared, the electrostatic speaker and the inductor type speaker.

382. Characteristics of a Loud Speaker. A good loud speaker must be able to respond to any frequency within a certain range, 30 to

7000 cycles, in a manner which is proportional to the input power at that particular frequency. Figure 1 illustrates the various frequencies as they relate to a piano keyboard. This means that there must not be resonance in any of the electrical circuits or mechanical parts of the speaker. Mechanical resonance in the mechanism will appear as electrical resonance in the electrical circuit, or vice versa, electrical resonance would seem to cause mechanical resonance in the mechanism. It will be remembered that the current in a resonant circuit is greatly increased when the circuit is tuned to resonance.

383. Magnetic Type. In the magnetic type of speaker which, in its simplest form, consists of a horseshoe magnet with windings which strengthen or weaken the poles according to the direction and strength of the current, the diaphragm, which consists of a disc of sheet iron, has resonance frequencies and tends to emphasize certain tones. A disc or plate has many types or modes of vibration so there may be many resonance peaks.

The condenser microphone has gotten away from these resonance peaks by using a stretched diaphragm in which the resonance peaks are at high frequencies out of the audible range. The electrical circuit to which the condenser microphone is connected is a high resistance removing the danger from electrical resonance. However, the output of the condenser microphone is very low. The stretched diaphragm necessarily makes the amplitude of vibration small and therefore the output of the speaker is small. It is therefore impossible to use this principle in speakers in the same manner as it is used in microphones.

Some speakers have used diaphragms with circularly pressed corrugations, rendering the diaphragm more pliable and in this manner getting greater amplitude.

The field in the neighborhood of the pole pieces varies as a high power of the distance from the poles, rendering the motion complex. If the strength of the pole increases the disc moves towards the pole and the attraction increases on account of the change in distance. The force, therefore, is not proportional to displacement as it should be for pure simple harmonic motion. Suppose a high note and a low note are sounded together. The disc vibrates with respect to the low note moving in and out. The disc must vibrate also in unison to the high note. When the disc is close to the

magnet due to the low note, the amplitude of the high note will be greater than the high note amplitude is when the disc is in opposite phase, due to the low note.

FIGURE 2. An early type of loud speaker. A Baldwin mica disc phone and a horn.

Taking everything into consideration it is difficult to get a magnetic type of loud speaker in which there will be no resonance peaks. These magnetic type speakers were coupled to horns and it was supposed that the horn by many twists and turns could make up the deficiency. Figure 2 is a loud speaker made of Baldwin mica disc phones and a horn.

384. Horns. A horn in its most simple form is a long cylindrical tube open at both ends. The moving diaphragm is at one end and the other is open as in an open organ pipe. The length of the tube is one half wave length. In a resonance column there is always a question of where the column ends. It is customary to add a certain fraction of the diameter of the tube to the length of the tube. This fraction depends to some extent on the frequency. In a flaring column or horn this uncertainty or variation with the pitch becomes more pronounced. The resonance column must be longer for low notes than it is for high notes. If the flare can be made so the length of the theoretical column is inversely proportional to frequency then the horn is resonant for all frequencies.

FIGURE 3. Exponential horn.

385. Exponential Horn. The exponential horn is one in which the length is, theoretically, inversely proportional to wave length. Figure 3 gives an exponential horn. To be resonant at low frequencies the horn must be very long. A long horn is unwieldy so it is twisted up into many forms in order to conserve space. The

assumption is that the twisting does not change the properties of the horn. A peculiar twist also makes a good talking point for the salesman.

The exponential horn is one in which the area of the cross section is proportional to the logarithm of the length. $A = \log_e (x+c)$ or $(x+c) = e^A$.

This is illustrated in Figure 4 in which a curve is plotted using length and area. If the area of the horn at the small end where it joins to the speaker unit is a certain area, for simplicity say one square inch, then at a certain distance, 1 foot, say, the area is 2 sq. in.; at 2 ft. it is 4 sq. in.; at 3 ft. 8 sq. in.; 4 ft. 16 sq. in. The area is doubled for each unit of length added. If the horn is extended until it is 11 feet long the cross section is 1924 sq. inches or if the horn has a square cross section the sides of the square are 32 inches. If 13 feet long the sides of the square are 64 inches. If 15 feet long the sides of the square are 10 feet 8 inches.

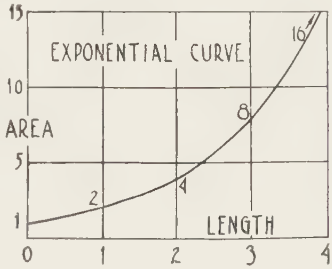


FIGURE 4.

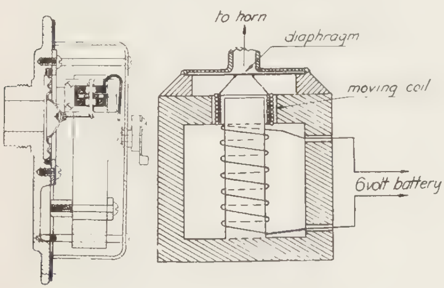


FIGURE 5.

386. *Dynamic Speakers.* The dynamic speaker consists of a floating coil in a radial magnetic field. The radial magnetic field is produced by a coil with a core and a magnetic shell shown in cross section Figure 5. The floating coil is wound on a light form and is supported so it can vibrate up and down. The coil in the modern dynamic speaker is fastened to a wide angled paper or parchment cone. This cone is supported at the rim with buckskin or soft leather. In this manner the cone can vibrate as a whole with a a rather large amplitude. The cone vibrates also in parts as a plate or bell. The floating coil has low impedance, low resistance

and a small number of turns. In this manner the resonant frequency of the coil is very high. By proper construction of the

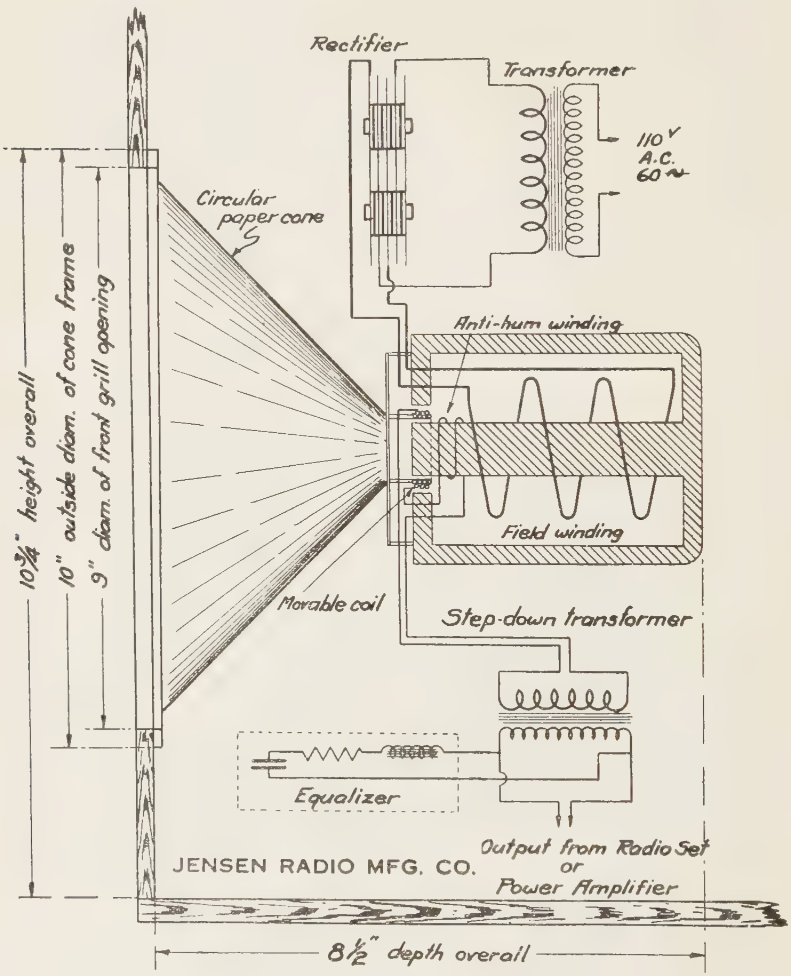


FIGURE 6.

cone the mechanical resonant frequencies are mostly eliminated or distributed fairly uniformly over the audio frequency band.

Figure 6 is a diagram of a high class dynamic speaker. Figure 7 gives response curves for this speaker. Two curves are shown taken by two observers on the same type of speaker. These curves show how curves may vary according to room, angle, and general conditions.

The field coil of the dynamic speaker requires direct current. This direct current can be furnished by a 6 volt storage cell or any other means such as 110 volt D.C. lighting circuit. As a usual thing the current is furnished from a 60 cycle lighting circuit

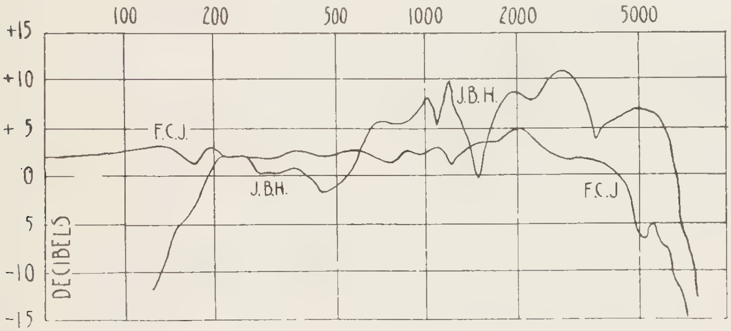


FIGURE 7.

employing some form of rectifier. In some sets this coil is made one of the choke coils in the B battery power supply for the receiving set.

The cone of the dynamic speaker should be fastened to a baffle board. The purpose of this baffle board is to prevent interference between the waves from the back and the front. Without the baffle board, regions of intense and minimum sounds can be detected if the speaker is emitting a sustained tone. Theoretically this baffle board should be infinite in dimensions. However, a board two or more feet in dimension will serve. If the speaker is placed in a closed cabinet, the cabinet will serve for the baffle board. For permanent installations a hole can be cut in the wall of a room over a closet door, and the speaker mounted in the closet, the hole being covered with a decorated screen of thin material.

387. The Inductor Dynamic Speaker. A new speaker which has

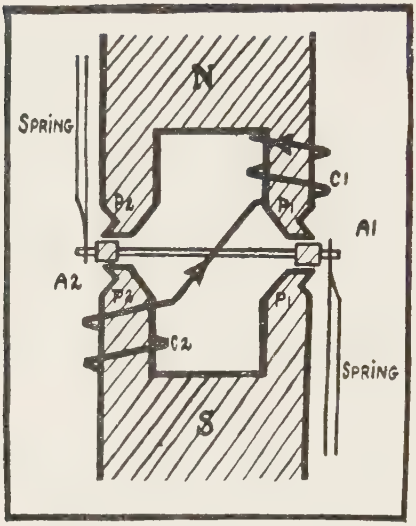


FIGURE 8.

appeared during the past year is known as the inductor dynamic speaker. The principle can be seen from Figure 8. A horseshoe magnet has its poles of peculiar shape. It will be seen that the poles are divided into two parts.

The inductor which consists of two pieces of magnetic material is supported on the ends of a metal rod. The distance between the two pieces is somewhat greater than the distance between the two poles. They are held in an unstable position, unstable with respect to the magnetic circuit, by means of two spring supports. If the current flows as indicated by the arrows in Figure 8, P_1 is strengthened and P_2 is weakened. This causes the inductor to move in the direction from A_1 to A_2. A reverse current will of course reverse the effects.

In this speaker the displacement is closely proportional to the force or current giving good response. The claim made for it is that it will give response equal to the dynamic speaker and that the cost and upkeep is relatively low. A permanent magnet is used and there is no need of a field current.

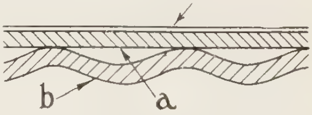


FIGURE 9.

388. The Electro Static Loud Speaker. A new speaker called the electro static loud speaker depends upon the electrostatic force between two plates of a condenser for its moving force. It consists of a corrugated plate, *a*, Figure 9 and over this a special rubber plate. This rubber plate is thin, somewhat like dental rubber. The back side of this has a special flexible conducting coating. In the figure, *b* is the rubber sheet, and *c* is the conducting coating. The sheet being very thin, the two "plates" of the condenser are brought very close together on the ridges of the

corrugated plate, *a*. When the plates are charged there is a tendency for the rubber to be sucked down into the valleys. This causes the vibrations which disturb the air.

To increase this action a permanent potential of a few hundred volts is maintained between the plates. This is similar to the condenser microphone. This D.C. potential is maintained from a rectifier in which a 201A tube is used as a two electrode tube. Figure 10 is an amplifier made by the Samson Elec. Co. which is designed to operate a loud speaker.

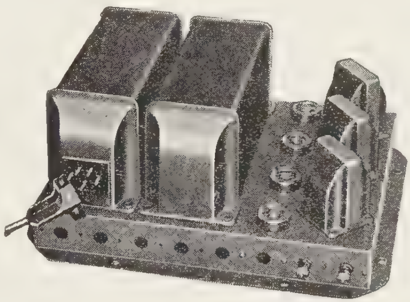


FIGURE 10.

389. Response Curves. A response curve is a curve which shows how a loud speaker responds to the various frequencies in the range of the human voice. It would seem that this would be a rather simple matter. All that is necessary is to produce the various tones with constant energy input and listen to the loudness produced by the speaker. The ear like the eye is not a very exact measuring instrument. The effect depends a great deal on the previous history of the ear. One is dazzled when he comes out of a dark room into the daylight. He is utterly blind when he goes from ordinary daylight into a poorly lighted room. The response of the ear like the eye depends upon the previous excitation of the ear, or upon the tones, which were sounded immediately before.

The method of measurement consists in energizing the loud speaker with current from a beat tone oscillator. The oscillator should be one which will give constant output at all frequencies. However a vacuum tube voltmeter can be placed across the speaker terminals and the oscillator adjusted to the same potential at all tones or a thermo instrument can be placed in series in order to keep the current constant. This does not necessarily mean that the input energy is the same, unless the speaker is a resistance load. If there is reactance in the circuit the reactance will vary with frequency and the energy will change from reading to reading.

The sound energizes a microphone Figure 11 and the amplified output is passed through a hot wire or thermo instrument and readings are taken. This assumes that the response curve of the microphone is constant, or that the amplifier has a straight line response curve, or at least that the curve is known.

In order to get this condition the circuits and loads must be balanced and tested.

The reading should be taken out of doors in an open field free from all noise and wind. It will be evident that in most cases this is impractical. The apparatus should at least be tested out of doors and then compared with the values obtained in the test room.

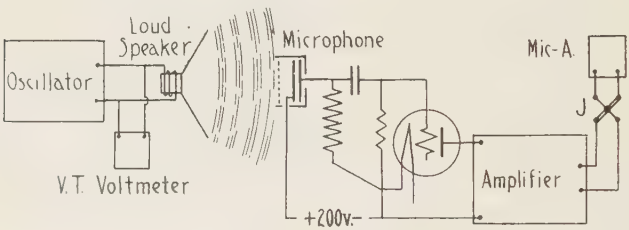


FIGURE 11.

In a room there will always be certain room patterns or standing waves formed by the various reflections which will give distorted results. These standing waves move in space as the frequency is changed and if a standing wave happens to fall on the microphone the response will be greater than if a minimum or destructive interference point happens to fall on the microphone. It is customary to pad the room with sound absorbing material and absorb the energy. If all were absorbed there could be no standing waves and the conditions would be the same as in an open field where the sound all goes out to infinity. In even the best padded rooms there is some reflection so all rooms have room patterns. If the room is large the reflections are more scattered and the patterns are not so pronounced.

An argument might be made that a padded room is not the same as an ordinary room and that a response curve made in a padded room will not show the actual conditions.

Another method suggests itself from the analogy of light. The intensity of a lamp may be made in a dark room with black walls

or the lamp may be placed in a spherical enclosure with a good reflecting surface. The sphere is filled with energy and the intensity of the light in the sphere is taken as a measure of the luminosity of the lamp. The apparatus might be set up in a room with reflecting walls and the total noise measured. This of course will assume that the walls reflect the same for all frequencies.

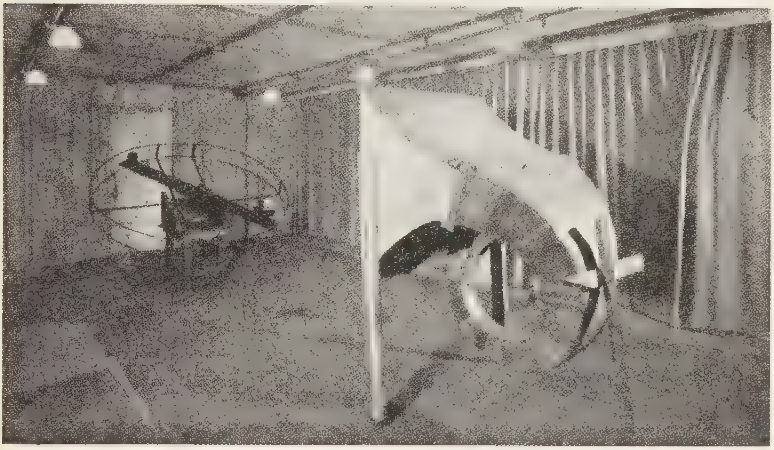


FIGURE 12. Sound Measuring Room of the Bell Laboratories. Note the revolving microphone and the exponential horn.

The microphone is usually placed at a fixed point in front of the loud speaker. It is found that if the microphone is moved to the side the intensity falls off with the angle. The speaker or horn seems to have a beam effect in that a large percent of the energy is projected out something like light from a spot light. The shorter the waves the more this beam effect. Long waves seem to spread. Directly in front the measured intensity of short waves is greater than the measured intensity of long waves. To the side, at certain angles, the reverse is true.

To avoid the room patterns and to get more of an average value over the entire beam the Bell Laboratories have devised a method in which the microphone is rotated about a circle several feet in diameter. The plane of the circle is inclined at an angle with the horizontal. If the period of the rotation about the circle is short compared to the time it takes for the junction to heat up to its

final value the readings will be average values over the entire space. This also eliminates or gives average values for the room patterns. Figure 12 shows a picture which will give the general details.

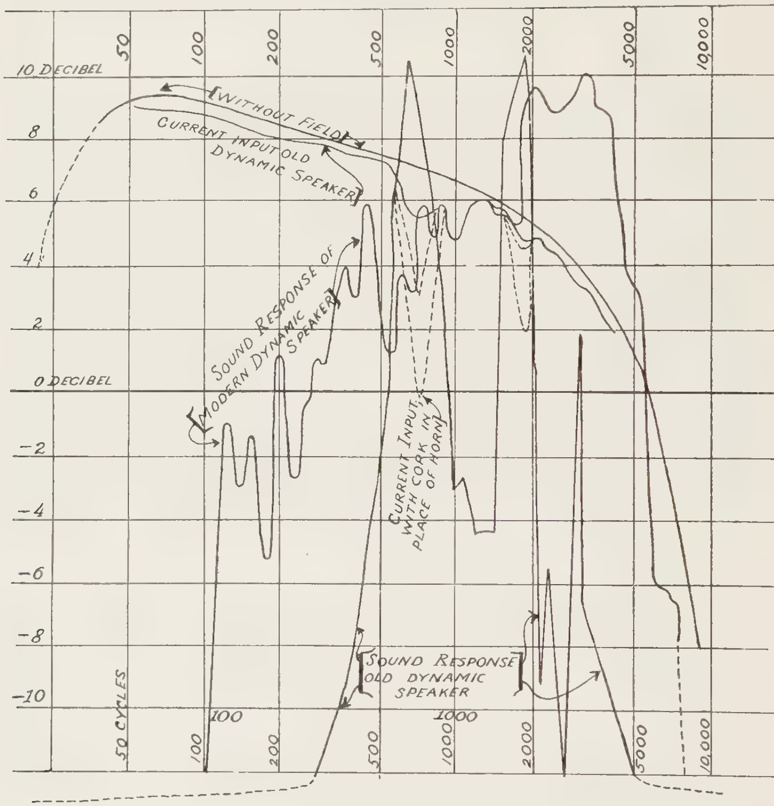


FIGURE 13. Curves showing current input for an old dynamic speaker and sound response for both old and modern dynamic speaker.

With field remove the current input is a smooth curve. With the field a decided diminution of current when the sound response is great. This is unusually large without horn and when the horn is replaced with a cork.

The response curves seem to be rather irregular due to the mangification of the ordinates.

The author suggests that if the microphone and loud speaker were mounted on the ends of a 2″ x 4″ board of suitable length and this as a whole were swung from the ceiling of a rather large room

and made to vibrate in a more or less "regular irregular" fashion the average reading of the thermo instrument would give the average response in an ordinary room. If it were arranged so that the loudspeaker could oscillate about a vertical axis through an angle of several degrees the beam effect would be averaged out.

Certain precautions should always be made. Tests should be made to see that there are no induction effects from the oscillator circuits; that there are no effects from vibrations of tubes. When the microphone is disconnected or covered with an absorbing covering there should be no response for the loudest sounds produced in the speaker.

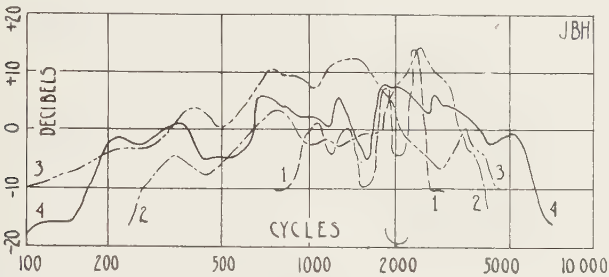


FIGURE 14.

A carbon microphone can be used but a condenser microphone will give more even response for all frequencies. See Chapters XIX and XXIV.

Curves are usually plotted on logarithmic paper in decibels. For definition of the decibel and method of handling data see Chapter XXVII.

In comparing curves the scale to which the curves are drawn should be noted. Figure 13 shows curves for an old dynamic speaker and a modern speaker. Impedance curves for the old dynamic speaker are plotted on the same sheet. The roughness of the curves are magnified by the scale used.

Figure 14 shows the response curves of four speakers. 1, is that of an early speaker which is primarily a short horn on a head set; 2, is a horn speaker; 3, is an early cone type speaker; 4, is a modern dynamic cone speaker.

Figure 7 shows two curves taken on the same type of speaker by different observers using different apparatus.

CHAPTER XXIX

RECTIFIED ALTERNATING CURRENT

390. Introduction. In transmitting stations which use tube oscillators, as most stations do, high potential direct current electromotive force is needed on the plate of the tube. When the E.M.F. is greater than a few thousand volts, say 2000, it is usually more convenient to use rectified alternating current than it is to use a direct current generator. The potential of alternating current can conveniently be made any value wished by means of a transformer. In the transformer there are no moving parts so it is much easier to insulate a transformer than it is to insulate the armature of a D.C. generator. Therefore it is more simple to make a rectifier than it is a high potential D.C. generator.

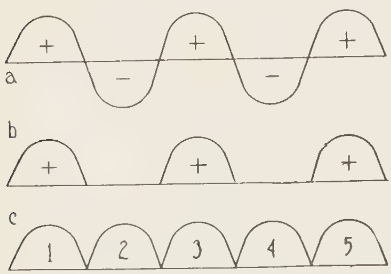


FIGURE 1.

Alternating current can be rectified by several relatively simple devices. Figure 1 (*a*) represents an alternating current of suitable voltage. This consists of a positive "hump" and a negative "hump" alternately. If this circuit is connected to the plate of an ordinary vacuum tube, the current flows when the plate is positive but there is no current when the plate is negative. The same will happen if we use a rectifying tube or a two electrode tube. The current can be represented by the diagram, Figure 1 (*b*). In this the current which flows is always in the positive direction but it is very irregular. The value varies from the maximum value to zero, the value being

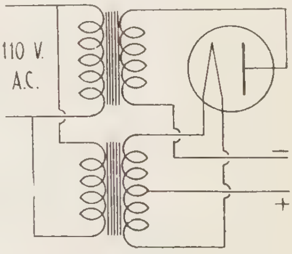


FIGURE 2.

zero half the time. The connection in this case is illustrated in Figure 2.

391. Complete Rectification. If the connection is as in Figure 3 we get complete rectification. The current can be represented by the diagram in Figure 1 (*c*). In this case we assume we have a special transformer with a central tap on the secondary coil. If two tubes are connected as in the diagram, Figure 3, the current flows through the tube, *a*, when the plate is positive, giving the humps, 1, 3, 5, etc. The current flows through the tube, *b*, when its plate is positive, giving the humps 2, 4, 6, etc. Thus the current which flows from the filaments of the tube is always in the positive direction. If the curve is 60 cycles A.C., there will be 120 humps per second. The rectified current is a pulsating D.C., making 120 pulsations per second. If this potential is used on the plate of a transmitter tube we will have M.C.W., because the potential of the plate is not constant. The high frequency current which we would get can be represented by Figure 4, Chapter XXIII.

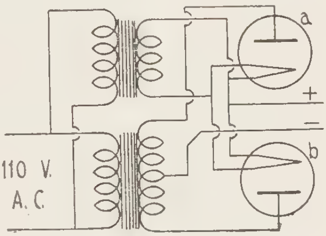


FIGURE 3.

392. Need of Filters. With this pulsating D.C. potential the transmitting station will be modulated almost as much as the code transmitter diagrammed in Figure 3, Chapter XXIII. If this were used on a broadcasting station, the modulation would be so loud it would drown out all the voice and music. Before this can be used it must be smoothed out by means of a filter. The filter consists of inductance in series and condensers in parallel. The diagram of the connections is given in Figure 4. The coils, *L*, are iron core choke coils. The effect of inductance tends to make the current constant.

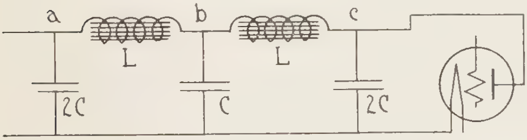


FIGURE 4.

The condensers, which have a capacity of one or more microfarads, act as a sort of storage tank for the excess electricity. When the current is increasing, there is a back E.M.F. in the coil. This raises the potential across the first condenser and it is charged up with a certain amount of electricity which is given out again when the current is decreasing and there is a forward E.M.F. in the choke coil. The second choke coil and second condenser act in the same general manner and the final result is, provided the coils and condensers have the proper inductance and capacity, a smooth direct current which can not be distinguished from that of a battery.

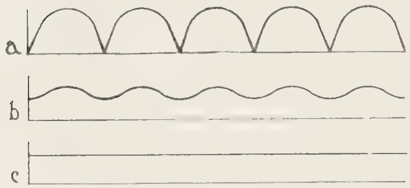


FIGURE 5.

The current at *a*, Figure 3, can be represented by diagram *A*, Figure 5; the current at *b*, Figure 4, can be represented by diagram *b*; the final current by the diagram, *c*.

393. Rectifying Tubes. The Radio Corporation of America's Kenotron 280, 281, etc., tubes are made especially for this purpose. Figure 1, Chapter X. They are made with filament and plate only and look very much like the ordinary three electrode tubes. Tubes with different numbers are made in various sizes for various voltage rectification.


FIGURE 6. A Rectifier Tube. 5000 to 10,000 volts.

Figure 6 is a two electrode rectifier which will handle potentials from 5000 to 10,000 volts.

Figure 7, Chapter XXVI, is a diagram of connections to a three electrode tube connected in an amplifying circuit. It will be noted that three transformers are needed,—one to supply the high potential A.C. to the plates of the rectifying tube, one to supply the filament current for the rectifying tubes, and a third to supply the filament of the three electrode tube in the amplifying circuit. The negative return can be connected to one side of the filaments, but it is much better to

have a connection to a mid-tap on the secondary of the filament transformers. If the negative returns through a choke coil just before entering the grid return, and if two condensers are connected in series across the filament of the tubes with the mid-point connected to the choke coil, the hum due to the A.C. in the filament can be much reduced.

In Figure 19 Chapter XXIV, in the diagram of the five kilowatt station, is shown a rectifier giving current at 10,000 volts potential. This is from a three phase 60 cycle line.

Mercury vapor lamps can be used as rectifiers. A new rectifying tube is coming into use which contains mercury vapor. This tube can be used for very high potentials. Figure 7 shows the UX866 tube which will rectify 8000 volts.

FIGURE 7. UX8 66R. C. A. Mercury Vapor rectifying tube.

394. B Battery Eliminators. B battery eliminators are devices to use rectified alternating current in the plate circuit of receiving circuits. They are in principle the same as the rectifier used with power tubes. Rectifier tubes may be used as rectifiers, or aluminum rectifiers may be used. The Raytheon tube is often used Figure 8. The Raytheon tube is a special rectifying tube which rectifies both sides of the A.C. current. It consists of two anodes in a special chamber filled with inert gas. This tube will rectify A.C. potentials of 200 volts to 250 volts and will furnish D.C. potentials up to about 150 volts. It has the advantage that no filament current is needed. The new UX280 and 281 tubes which do not require so much filament current have displaced the Raytheon to some extent. After rectification the current must be passed through the usual smoothing out filter of inductances and condensers. Since, in a receiving set the plate potentials of the various tubes vary from 20 volts to near 150 on the detector on the last power tube, provision must be made to get various potentials. This is done by means of resistances in series with the

circuit. Figure 9 is a diagram of the circuit. The values of the resistances and inductances are given in the figure. Figure 23, Chapter XXV, gives the values of the resistances used in the battery eliminator used in the Radiola 64.

FIGURE 8. Raytheon rectifying tube. This tube rectifies both sides of the A.C. The tube is filled with an inert gas. The rectification depends upon the "point to plane" principle.

395. Aluminum Rectifiers. A very simple and efficient rectifier can be made in a glass jar with lead and aluminum electrodes. Various electrolytes can be used. One of the best and cheapest is a dilute solution of ordinary baking soda. One of the worst troubles is to get pure aluminum for the electrode. The area of the aluminum surface exposed to the electrolyte should be one square inch for 40 milliamperes of current. The potential on each cell should not be over 50 volts. For 110 volts A.C., at least two cells should be in series. For complete rectification utilizing both sides of the alternating current wave, four cells can be used and connected as in Figure 10. The D.C. current flows into the lead electrode and out of the aluminum electrode. By tracing the direction of the current it will be seen that each "hump" on the A.C. passes through the storage battery in the D.C. circuit, in the proper direction to charge the battery. It will be

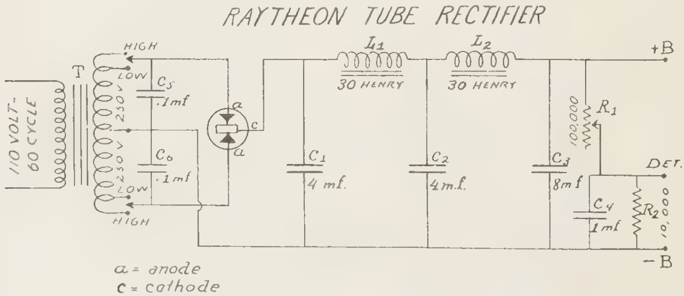


FIGURE 9.

noted that the current in each case flows through two of the cells and the other two block the current from flowing in the negative direction.

For higher voltages more cells are placed in series. The four arms of the bridge should be the same. Thus with eight cells full wave rectification will be obtained with voltages up to 200 volts. If 1000 volts is to be rectified, each arm should have 10 cells in series, or a total of 40 cells. With 80 cells one should get plate supply of about 2000 volts for a UV205, 250 watt tube. The area of each aluminum plate should be at least one square inch for one

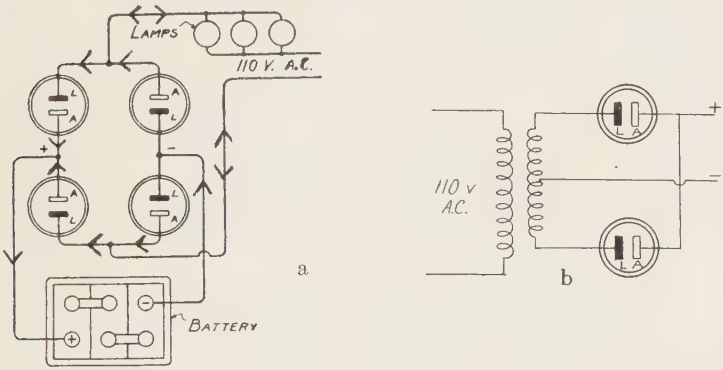


FIGURE 10.

power tube and proportionally increased if more than two tubes are used. The smoothing out filter is the same as for any rectifier.

An aluminum rectifier has the characteristics of a large condenser and as a usual thing it is easier to filter out the ripples when using aluminum rectifiers than when other rectifiers are used.

The rectification is due to a film or coating of oxide on the aluminum. The rectifiers must be formed when first used. Large resistance is placed in the circuit to cut down the voltage at first. This is gradually removed as the film is formed. If a D.C. ammeter and an A.C. ammeter are placed in series with the output circuit, the D.C. ammeter will at first read nearly zero while the A.C. meter will read a rather large current. As the film is formed the two meters will tend to read the same. When the film is fully

formed the two should read the same, indicating that the rectification is complete. The resistance should be removed until the current is the desired output of the rectifier, 40 milliamperes per square inch of aluminum surface. The efficiency of the aluminum rectifier falls off very rapidly with temperature increase. The rectifier should not be used when warm.

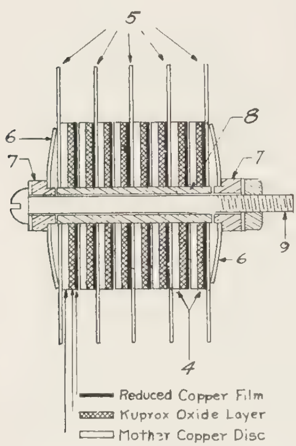


FIGURE 11.

396. Trickle Chargers. Trickle chargers are usually rectifiers of some sort which charge the *A* storage battery continuously at a very slow rate. A continuous, slow charge is injurious to storage batteries and will ruin the battery in a few months. A charger whch charges the battery at a comparatively fast rate is much better for the battery. An automatic switch which will turn the charger on when the battery is nearly discharged and off when fully charged is ideal. Battery eliminators tend to be noisy unless a good filter is used. There is nothing quieter than the good old fashioned A and B batteries.

397. Copper Oxide Rectifiers. The copper oxide rectifier has the advantage that it requires no filament current and is dry, there being no electrolyte to spill or creep over. Figure 11 shows a diagram of the rectifier. These rectifiers can be built for any voltage simply by increasing the number of plates. They can be connected in any of the bridge forms so as to rectify both sides of the A.C. potential. They are used as B and A battery eliminators. They are also used in loud speakers to rectify the magnetizing current, or field current.

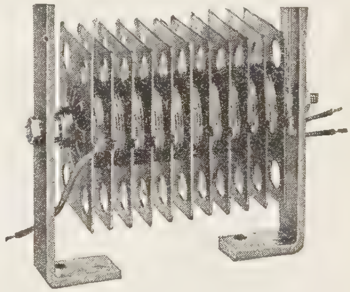


FIGURE 12.

Figure 12 shows a Kuprox rectifying unit as manufactured by the Kodel Electric and Manufacturing Company. Figure 13 is a Kuprox *ABC* power pack for supplying electrical energy to a modern receiver.

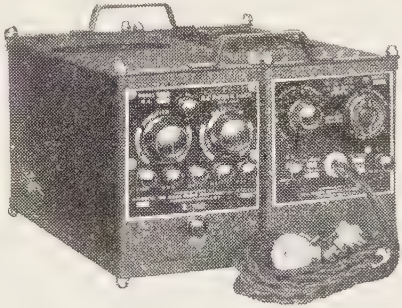


FIGURE 13.

The tendency seems to be to do away with all D.C. batteries and generators and to use rectifiers instead. It is remarkable that the plate potential on a receiving set, where the amplification is very great, can be made so near constant that the hum can not be heard. A diagram of almost any receiving set, as well as the diagram of a transmitter, will give the diagram of a rectifier.

CHAPTER XXX

APPLICATIONS OF THE VACUUM TUBE

398. Long Distance Telephone. One of the first places where the three electrode vacuum tube was used was in the long distance

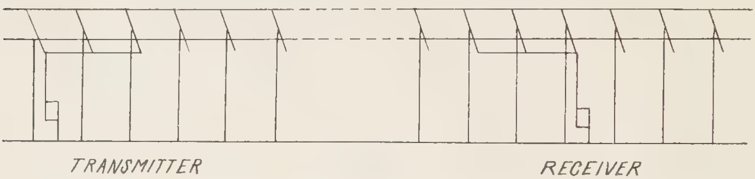


FIGURE 1.

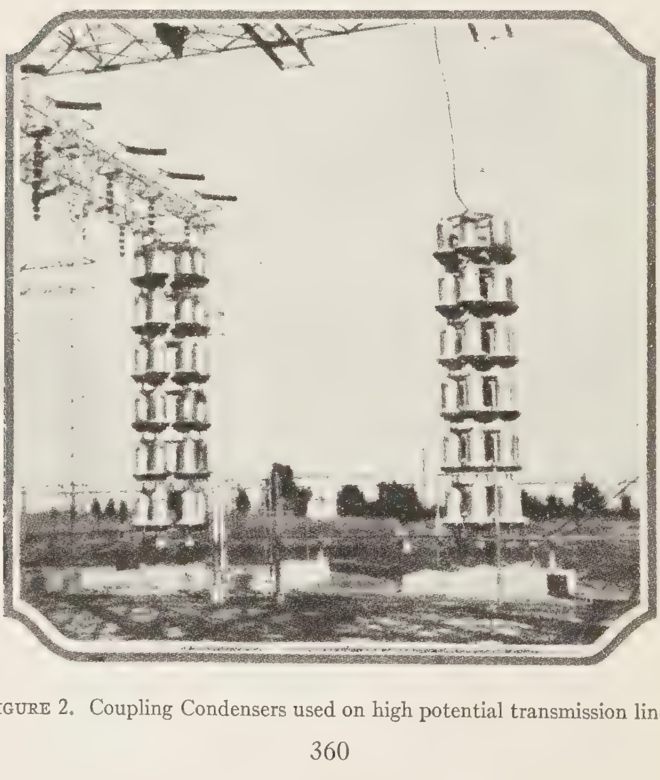


FIGURE 2. Coupling Condensers used on high potential transmission lines.

telephone lines. In 1915 the first long distance telephone call was transmitted across the U. S. There is a certain amount of loss in signal strength or attenuation on the lines and every few hundred miles it is necessary to amplify the speech in order that the attenuation does not place the intensity below the line noises. The amplification at a repeater station is such that the power does not fall below about 500 microwatts at the distant receiving station. The power amplification at the repeater station is from 4000 up to 10000 microwatts depending on the distance and line construction between the two points.

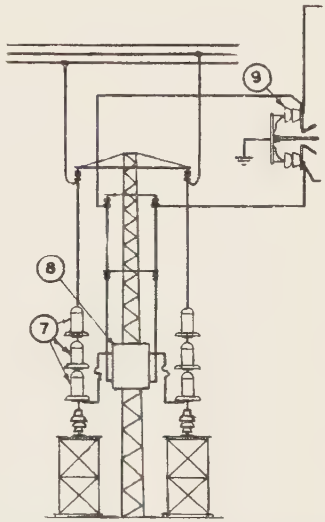


FIGURE 3. Showing method of connecting coupling condensers between power line and carrier telephone.

Between New York and San Francisco there are twelve repeating stations. It is figured that if the there were enough power put on the lines at New York so that San Francisco could receive with the usual intensity it would take more energy than that received by the earth from the sun. It is impossible to furnish enough energy

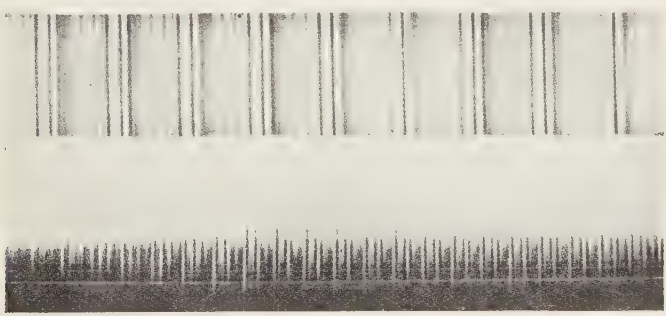


FIGURE 4. Photographic records of sound may be either of constant width and varying density, shown above, or of constant density and varying width, shown below.

at the starting point to transmit long distances. Wire telephone depends upon the tube for long distance work.

399. Carrier Current Transmission. Wired Wireless. The principle of radio transmission has been applied to wire lines. The wire instead of the ether serves for carrier of the radio frequency current or impulses. Diagrammatically the system may be illustrated by Figure 1 which represents a power line and a short line parallel to it.

The short line is connected to a radio frequency generator. The two parallel lines serve as the plates of a condenser of rather low capacity through which the radio current flows to the line. At the receiving end the receiver is connected to the short line and the radio frequency current flows from the power line to the receiver.

The intensity of the signal need not be very strong at the receiver end since it can be amplified and detected in the same general manner as in ordinary radio. The set can be tuned and the signal amplified exactly as in radio.

FIGURE 5. The sound is recorded on the film at the left of the pictures.

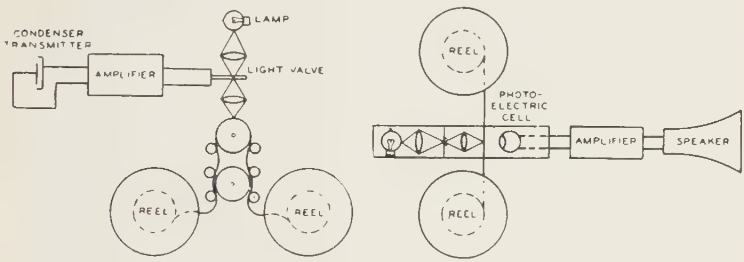
Carrier current transmission has been applied to lines and cables where the cost of erecting lines is excessive. A single line can carry as many messages as there are wave channels which do not interfere one with the other. The analogy may be made to the ether of space. There should be as many channels on any wire system as there are channels in the ether.

Power companies use carrier current transmission to communicate between the power stations. The lines over which they communicate may be carrying power at a potential of hundreds of thousands of volts at the same time.

Figure 2 is a picture showing the coupling condensers on a high potential line. Figure 3 shows the same thing diagrammatically.

400. Talkies. Musical or talking moving pictures may be divided into two general classes, the synchronized and the unsynchronized. The unsynchronized musical pictures are those in which the operator selects a phonograph record which will go with the picture.

The operator is provided with a number of records of various kinds. The instructions with the film tell him the general class of record to select. Only certain types of films can be used in this manner.



Diagrammatic sound recorder. Diagrammatic sound reproducer.

FIGURE 6.

The synchronized pictures can be divided into two general classes. Those which use records much the same as phonograph records with an electrical pick up and an amplifier and those where the sound is recorded on the film. The record and the film are made at the same time and both are connected together so as to run in the same manner as when they were produced. The records look much as the regular records. They however run at a different speed and in the reverse direction.

In light recorded films there are two classes. One in which the intensity of the light varies making the intensity of the film variable and the other in which the light is made to vibrate making the developed film look something like a saw with teeth.

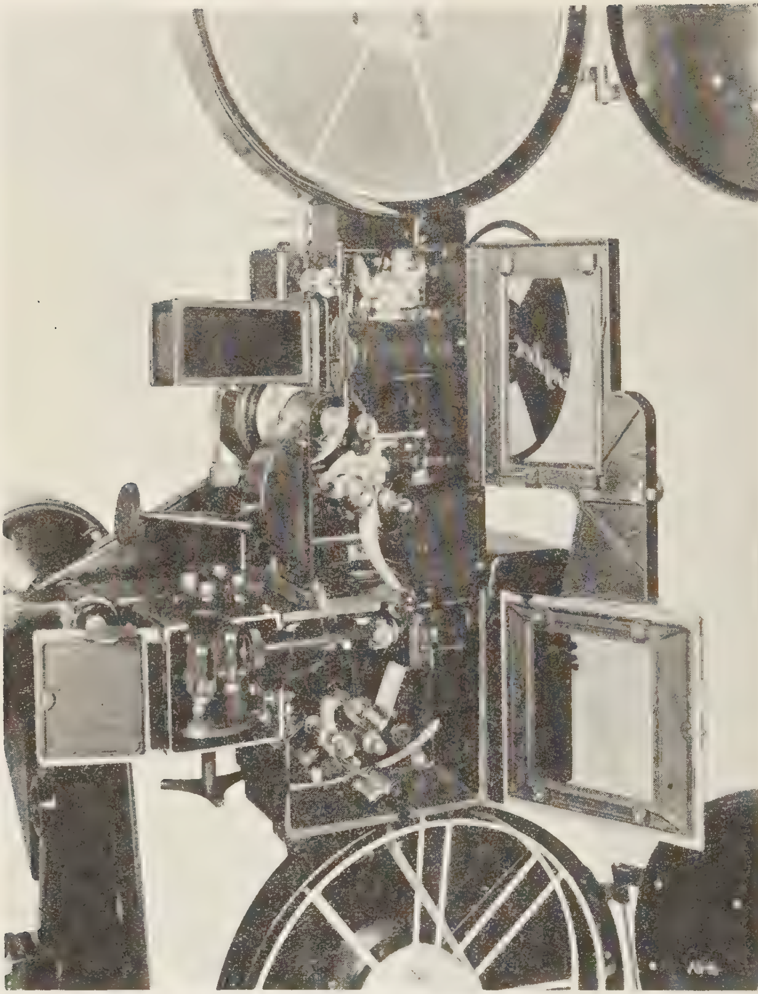


FIGURE 7. RCA Photophone sound attachment mounted on a standard commercial projector. The sound attachment is located directly above the lower takeup magazine.

Notice the arrangement of the three exciter lamps in the rear housing to the left of the center section of the attachment. These lamps are employed to furnish the illumination for the reproducing process. The three-lamp mounting is an exclusive RCA Photophone feature, permitting instant replacement by a prefocused lamp in the event the lamp in use fails. The center section of the attachment contains the slit and optical system, and sound gate through which the film travels. The section to the right houses the photo-electric cell.

Figure 4 is a reproduction of the two film records. Figure 5 is an R.C.A. photophone film showing the sound record on the side of the film.

Figure 6 shows a diagram of the scheme of recording and also the projector.

Figure 7 is a closeup of the projector and Figure 8 is a battery of loud speakers on the stage.

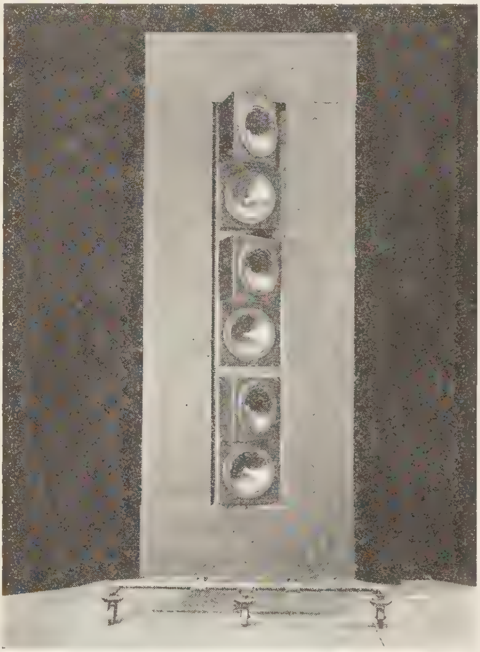


FIGURE 8. RCA Photophone uses exclusively the moving coil cone loudspeaker shown in this illustration. It is an electro-dynamic reproducer of highly efficient frequency range and great volume capacity. Batteries of these loudspeakers are mounted with the picture screen, a bank of loudspeakers on each side of the screen.

401. Television. In radio television the carrier wave is modu lated by the change of intensity of light in a photo-electric cell.

A photo-electric cell is a tube which has a deposit of sodium, potassium, or other substance which will emit electrons when light shines on it. Figure 9 shows a photo-electric cell. The photo sensitive material is deposited on the inside of the bulb. A portion of this bulb or window is made free from this deposit so the light can shine in.

If the central electrode is connected to the positive terminal of a battery and the negative is connected to a negative terminal which is electrically connected to the photo material, a current will flow through the circuit when light enters the cell. The number of electrons, and consequently the current, is proportional to the intensity of the light.

If this cell is connected to an amplifier and then to the modulator tube of a transmitting station the modulation of the carrier wave will be proportional to the intensity of the light.

At the receiving end the modulated carrier wave is received the same as radio telephone is received except after amplification the received signal is made to vary the intensity of a neon lamp instead of operating a loud speaker. The neon lamp, Figure 10, is a vacuum bulb which is filled with neon gas. This bulb has two terminals and glows much like a Geissler tube does when a potential is placed on the terminals.

FIGURE 9. Photoelectric cells are used in television and in Photophone.

When this is connected to the amplifier the potential of the terminals varies with the received current causing the light intensity to change in the same manner. In this manner a varying light at the transmitter caused a varying intensity of a lamp at the receiving station. A flickering lamp, however, which flickers very fast seems to glow steadily. Some thing else must be introduced between the two lamps.

The receiver and transmitter are provided each with a scanning disc. Figure 11. The scanning disc is a disc of metal which has a number of holes (20 to 48) drilled in it at equal angular distances so as to form a spiral. The holes are of such size that when the disc is rotated the area swept out by the first hole just touches the area swept out by the next hole. In this manner the areas swept out by the various holes cover a circular band an inch or so wide. Figure 12 is a schematic diagram of the sender and receiver.

The light from an intense lamp falls on the face of the subject through a hole in the scanning disc. As this disc is rotated light through the top hole sweeps across the top of the head then light from the second sweeps across the head a little lower down and as the disc makes one rotation the entire face is successively covered

with light, or the face is canned. The disc is rotated twenty or more times per second so the face is scanned several times per second.

The reflected light from the face is caught by the photo-electric cell. Thus the current in the photo-electric cell depends upon the reflecting power of the face which varies from place to place on the face.

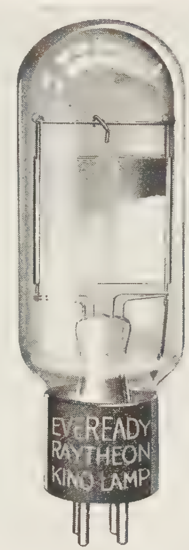


FIGURE 10. The light from a neon lamp varies with potential on the lamp.

The light given off by the neon lamp at the receiver varies in the same manner as the light caught by the cell. A second disc is placed in front of the lamp. This disc is in exact synchronism with the first disc. The first hole passes past the lamp at exactly the same instant the first hole in the transmitted disc passes over the face. Thus the light from the lamp that passes through this first hole varies in intensity in the same manner as the light caught from the face by the cell. The lamp is bright when the light passes a white portion of the face and is dark when the light shines on a dark portion. Since the two discs are exactly in synchronism due to persistence of vision, one sees the image of the face.

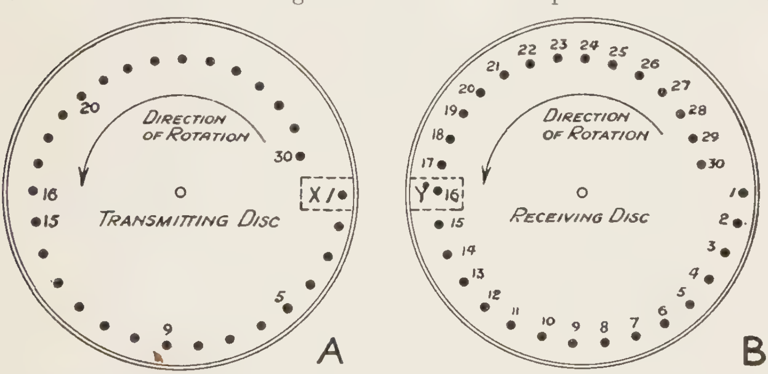
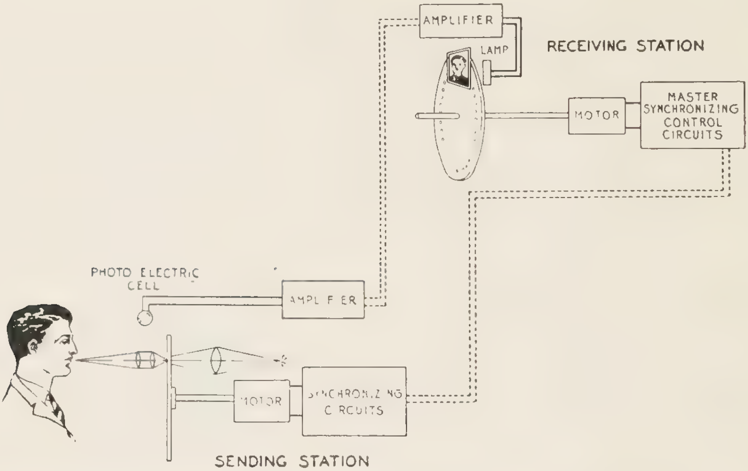


FIGURE 11. Scanning discs. The two discs must run synchronously.

Figure 13 shows a setup for transmitting a bright object such as a filament of a lamp. To transmit a face as in Figure 10 one



Transmitting apparatus for television as arranged for its first demonstration, April 7, 1927, in the auditorium of the Bell Laboratories

FIGURE 12.

needs a very intense source of light and a number of large photo-electric cells. Figure 14 shows the last stage of a receiver.

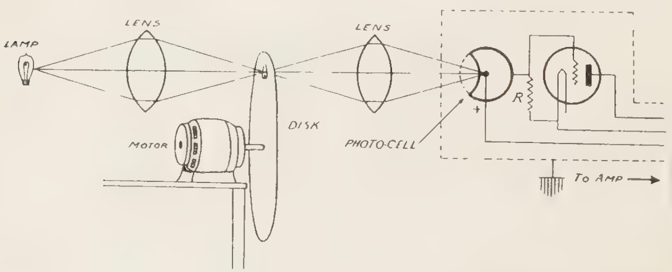


FIGURE 13.

Any sort of a receiver will do which will work on the short wave on which the picture is transmitted. The amplification must be enough to work a loud speaker.

One of the hardest things to do is to keep the receiving motor in synchronism with the transmitting motor. If all power stations

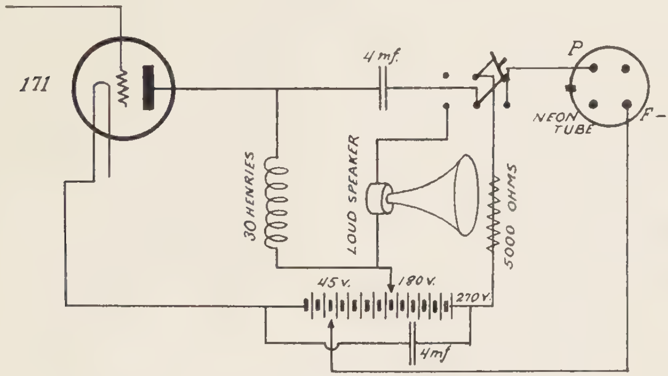


FIGURE 14.

were connected together so as to run at the same exact frequency then synchronous motors would be ideal.

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